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Genome-wide association analysis for quantitative trait loci influencing Warner–Bratzler shear force in five taurine cattle breeds

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Summary

We performed a genome-wide association study for Warner–Bratzler shear force (WBSF), a measure of meat tenderness, by genotyping 3360 animals from five breeds with 54 790 BovineSNP50 and 96 putative single-nucleotide polymorphisms (SNPs) within *μ-calpain* [HUGO nomenclature *calpain 1, (mu/I) large subunit*; *CAPN1*] and *calpastatin* (*CAST*). Within- and across-breed analyses estimated SNP allele substitution effects (ASEs) by genomic best linear unbiased prediction (GBLUP) and variance components by restricted maximum likelihood under an animal model incorporating a genomic relationship matrix. GBLUP estimates of ASEs from the across-breed analysis were moderately correlated (0.31–0.66) with those from the individual within-breed analyses, indicating that prediction equations for molecular estimates of breeding value developed from across-breed analyses should be effective for genomic selection within breeds. We identified 79 genomic regions associated with WBSF in at least three breeds, but only eight were detected in all five breeds, suggesting that the within-breed analyses were underpowered, that different quantitative trait loci (QTL) underlie variation between breeds or that the BovineSNP50 SNP density is insufficient to detect common QTL among breeds. In the across-breed analysis, *CAPN1* was followed by *CAST* as the most strongly associated WBSF QTL genome-wide, and associations with both were detected in all five breeds. We show that none of the four commercialized *CAST* and *CAPN1* SNP diagnostics are causal for associations with WBSF, and we putatively fine-map the *CAPN1* causal mutation to a 4581-bp region. We estimate that variation in *CAST* and *CAPN1* explains 1.02 and 1.85% of the phenotypic variation in WBSF respectively.

Keywords beef, *Bos taurus taurus*, calpain 1, (mu/I) large subunit, calpastatin, genome-wide association, haplotype, meat tenderness, quantitative trait loci, single-nucleotide polymorphisms, Warner–Bratzler shear force.

Introduction

Consumer assessment of beef quality, palatability and overall eating satisfaction is significantly influenced by tenderness (Huffman *et al.* 1996; Weston *et al.* 2002; Moser *et al.* 2004; Smith *et al.* 2006), and consumers have indicated a willingness to pay a premium for 'guaranteed tender' steak (Boleman *et al.* 1997; Mintert *et al.* 2000; Miller *et al.* 2001; Platter *et al.* 2005). Inadequate tenderness has consistently been identified in National Beef Quality Audits as a priority quality challenge (Lorenzen *et al.* 1993; Roeber *et al.* 2000; Shook *et al.* 2008) because consumers consider tenderness to be the single most important component of meat quality and will substitute protein sources motivated by their dissatisfaction from the purchase of a tough cut (Miller *et al.* 1995; McKenna *et al.* 2002).

To address these concerns, researchers have identified quantitative trait loci (QTL) for Warner–Bratzler shear

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force (WBSF) measurements on the longissimus dorsi muscle on chromosomes 2, 4, 5, 7, 10, 11, 15, 20, 25 and 29 (Casas *et al.* 1998, 2000, 2001, 2003; Keele *et al.* 1999; Rexroad *et al.* 2001; Alexander *et al.* 2007; Davis *et al.* 2008; Gutierrez-Gil *et al.* 2008; Gill *et al.* 2009, 2010). However, from these reported QTL, DNA marker tests have been developed and commercialized only from *calpastatin* (*CAST*) on chromosome 7 and *calpain 1, (mu/I) large subunit* (*CAPN1*) on chromosome 29 (Page *et al.* 2002, 2004; White *et al.* 2005; Casas *et al.* 2006; Van Eenennaam *et al.* 2007). While these commercialized marker tests are predictive of tenderness in both *Bos taurus taurus* and *B. t. indicus* breeds, it appears that they are not causal for the detected associations with tenderness (Casas *et al.* 2003). However, the estimated genotypic associations estimated for these markers are large, with an average difference of 0.15 kg in WBSF between alternate homozygotes in independent studies involving several breeds (Casas *et al.* 2006; Morris *et al.* 2006; Van Eenennaam *et al.* 2007; Johnston & Graser 2010). While positional candidate genes on other chromosomes have been investigated (Rexroad *et al.* 2001; Stone *et al.* 2005), none have resulted in commercial tests.

To assist beef breeders to make efficient and large changes in tenderness, DNA assays must be developed that can reliably predict the genetic variation in tenderness without regard to the breed composition of an animal. To address this need, we genotyped 3360 animals representing 114 half-sib families produced by the American Angus Association (AAA), American Hereford Association (AHA), American Simmental Association (ASA), American International Charolais Association (AICA) and the North American Limousin Foundation (NALF) as part of the National Cattlemen's Beef Association (NCBA) sponsored Carcass Merit Project (CMP) to develop prediction equations for the implementation of genomic selection (Meuwissen *et al.* 2001) and to identify genomic regions associated with tenderness. This study reports genomic regions detected as being concordant across breeds, which putatively harbour candidate genes that influence tenderness and which could be targeted for the development of diagnostic assays. We also dissect variation within *CAST* and *CAPN1* in order to identify the genomic regions most likely to harbour the causal variants influencing beef tenderness.

Materials and methods

Animals and phenotype

A total of 3360 animals representing five of the breed associations participating in the NCBA-sponsored CMP were selected for genotyping based on the availability of WBSF data and DNA samples (Table 1). The design of the CMP project has previously been described by Minick *et al.* (2004); however, only the Angus and Hereford samples represent purebred populations, with the Continental breeds being represented by crossbred progeny, with Simmental, Charolais and Limousin sires mated to predominantly commercial Angus cows. Meat tenderness was measured as WBSF (kg) of longissimus dorsi steaks at day 14 post-mortem as previously described (Wheeler *et al.* 1998; Minick *et al.* 2004). Muscle samples, extracted DNA samples and carcass phenotypes produced in the CMP and owned by the AAA, AHA, ASA, AICA and NALF were transferred to the University of Missouri. All CMP animals had blood samples drawn at weaning, from which DNA was extracted and tested to validate the identity of their sires. Additionally, a muscle sample was taken at slaughter at the capture of phenotype data on most of the animals, and DNA extracted from a subset of the muscle samples was previously genotyped and compared with the genotype profiles produced from the corresponding blood samples to validate the identity of each carcass. This process identified that about 10% of animals or carcasses were misidentified (Thallman *et al.* 2003) likely due to changes in the order of carcasses because of 'rail-outs' at packing plants. To resolve this issue, we extracted genomic DNA from 2940 muscle samples taken from the phenotyped carcasses by proteinase K digestion followed by phenol–chloroform–isoamyl alcohol extraction and ethanol precipitation (Sambrook *et al.* 1989). The remaining 420 DNA samples were extracted from the blood, but these samples had previously been DNA-typed and successfully matched to the sample taken at harvest.

Genotypes

All samples were genotyped using the Illumina BovineSNP50 BeadArray (Matukumalli *et al.* 2009) for 54 790 single-nucleotide polymorphisms (SNPs) and a custom-designed Illumina GoldenGate assay incorporating 96 putative SNPs located within 186 kb of *CAST* and *CAPN1* (Table S1), discovered either as part of the bovine genome sequencing project or through directed *CAPN1* resequencing studies at the US Meat Animal Research Center at Clay

Table 1 Animal counts, mean phenotype and estimates of additive genetic variance and heritability by breed.

	Count		Warner–Bratzler shear force (kg)		
Breed	Animals[1]	Sires	Average	σ^2_A	h^2
Angus	660 (651)	20	3.74	0.22	0.52
Charolais	702 (695)	18	4.41	0.23	0.46
Hereford	1192 (1095)	29	4.75	0.15	0.17
Limousin	285 (283)	23	4.28	0.07	0.09
Simmental	521 (516)	24	4.36	0.06	0.08
All Breeds	3360 (3240)	114	4.37	0.17	0.25

[1]Numbers of animals with genotype call rate $\geq$0.85 in parentheses.

Center, NE (Page *et al.* 2002; White *et al.* 2005; Casas *et al.* 2006). Several of the putative SNPs identified in the genome sequencing project were not variable (Table S1), and we were much more successful in fine-mapping *CAPN1* than *CAST*. All genotypes were called in the Illumina GENOMESTUDIO software. Genotypes were filtered according to their unique localization to an autosome or the X chromosome in the University of Maryland sequence assembly (UMD3.0; Zimin *et al.* 2009), call rate (>0.89) and minor allele frequency >0.01 within each breed. Animals were excluded if their individual genotype call rate was <0.85. The call rate of >0.89 for SNP filtering was used to ensure that all commercialized tenderness SNPs were included in the analysis. After filtering, the data set comprised 40 645 SNPs assayed in 3240 animals (Tables 1 and S2).

Analysis

FASTPHASE v1.2.3 (Scheet & Stephens 2006) was used with UMD3.0 coordinates to phase all genotypes and impute the 0.89% of missing genotypes. The complete set of genotypes was then used to generate a genomic relationship matrix (G) across all breeds using the first of the methods described by VanRaden (2008) with a modification allowing the inclusion of X-linked loci as described below.

Warner–Bratzler shear force phenotypes were analysed under a single-trait mixed linear animal model in which the genomic relationship matrix was used to represent the realized identity by descent among the animals. The model fit was $y = X\beta + Zu + e$ where y is a vector of WBSF measurements, β is a vector of fixed contemporary group effects defined as breed × herd of origin × sex of calf × slaughter date, u is a vector of random additive genetic merits, and e is a vector of random residuals. The matrices X and Z are incidence matrices relating observations to levels of the fixed and random effects, and we assume that $\mathrm{Var(u)} = \mathrm{G}\sigma^2_\mathrm{A}, \mathrm{Var(e)} = \mathrm{I}\sigma^2_\mathrm{E}$ and $\mathrm{Cov(u, e)} = 0$. Restricted maximum likelihood was used to estimate the variance components σ^2_A and σ^2_E and iteration on the variance component estimates continued until the estimate of heritability $h^2 = \sigma^2_\mathrm{A}/(\sigma^2_\mathrm{A} + \sigma^2_\mathrm{E})$ had converged to four significant figures. At convergence, the GBLUP of the vector of SNP allele substitution effects (ASEs) was obtained as $\hat{\alpha} = (2\Sigma_i p_i q_i)^{-1}\mathrm{M}'\mathrm{G}^{-1}\hat{u}$ where p_i is the frequency of the A allele at the ith SNP (genotypes at each SNP are called in A/B space by the GenomeStudio software), $q_i = 1 - p_i$, elements of the ith column of M are $2q_i$, $q_i - p_i$ and $-2p_i$ for AA, AB and BB genotypes at autosomal and pseudoautosomal loci (VanRaden 2008) and are q_i and $-p_i$ for AY and BY genotypes at X-linked loci in males, and $\hat{u}$ is GBLUP of u. Analyses were performed both within each breed and across all breeds.

The variance component associated with SNP ASEs is $\sigma^2_\mathrm{M} = (2\Sigma_i p_i q_i)^{-1}\sigma^2_\mathrm{A}$, and for each SNP, the predicted ASE was normalized to a t-like statistic as $t_i = |\alpha_i|/\sigma_M$. These values are included in Table S2 and are shown in the Manhattan plots in Figs 1 and S1.

Across-breed comparison of putative QTL regions

To determine whether common QTL influence WBSF across breeds, we ranked the t_i values estimated in the within- and across-breed analyses and then identified SNPs for which the t_i values ranked in the top 500 (1.2%) of SNP ASEs in the across-breed analysis. For each of the regions tagged by these SNPs, we declared the region to harbour a QTL if at least three SNPs from different within-breed analyses had ASEs ranked in the top 500. While linkage disequilibrium (LD) decays to ~0.1 within less than a 500-kb distance within breeds of distantly related individuals (McKay *et al.* 2007), many of the individuals incorporated into these analyses are half-sibs (Table 1), which leads to a much greater extent of LD because of large common chromosomal segments transmitted by the sires to their progeny. Additionally, we wanted to allow for the possibility that more than one QTL could be present within any one genomic region. Accordingly, we allowed the region size to vary up to 5.7 Mb (average 1.7 Mb) as determined by the signatures of the detected within-breed SNP ASE ranks. Furthermore, within each region, we did not expect to find the same SNP to be most strongly associated with WBSF, because differences in SNP and QTL allele frequencies between breeds (Table S2) can lead to different patterns of LD in different breeds.

Candidate genes

Genomic regions identified as being associated with WBSF in at least four breeds were analysed using the NCBI

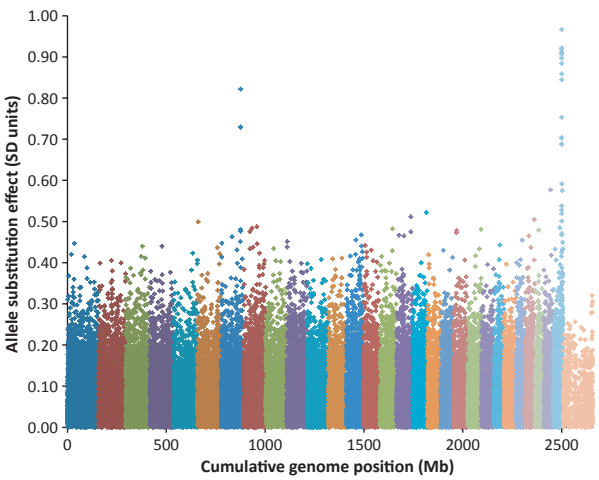

Figure 1 Manhattan plot of single-nucleotide polymorphism (SNP) allele substitution effects estimated in the across-breed analysis and normalized by the square root of the estimated SNP variance component.

Entrez Map Viewer (accessed 07/06/2011) to identify potential candidate genes for tenderness.

CAST and *CAPN1*

A 1.48-Mb region of BTA7 harbouring 28 SNPs spanning *CAST* and a 2.64-Mb region of BTA29 harbouring 93 SNPs spanning *CAPN1* were found to contain loci for which SNP ASEs ranked in the top 500 in the within-breed analyses. To allow haplotype-based analyses, we expanded the regions to 44 SNPs spanning 2.86 Mb for *CAST* and 100 SNPs spanning 3.12 Mb for *CAPN1* (Table S3). We first analysed each SNP individually by including allele effects (the difference between the two estimated allele effects is the ASE for the SNP) in β, in addition to the contemporary group effects, and then we included haplotype effects for windows of nine contiguous SNPs using phase information estimated by FASTPHASE. The haplotype model was sequentially fit by sliding the nine SNP window through each region one SNP at a time, and the statistics computed for each window were assigned to the 5th SNP located at the centre of each window. In both cases, the analysis was performed using the previously estimated variance components (Table 1), and *F*-tests for SNP or haplotype effects were constructed from the difference between model sums of squares including and excluding the fitted SNP or haplotype effects, the difference in number of parameters between the fitted models and the estimated residual variance for the full model. Because the number of detected haplotypes varied throughout each region (Table S3), the window producing the largest model sum of squares does not necessarily result in the largest *F*-statistic or $-\log_{10}P$-value (because the numerator mean square can be significantly influenced when its degrees of freedom are small but vary between tests). To avoid this, we computed the percentage of phenotypic variation explained by each window through the region from the ratio of the window to phenotypic sums of squares, where the window sum of squares was estimated as the difference between model sum of squares including and excluding haplotype effects for the nine SNP window and the phenotypic sum of squares was estimated as the total sum of squares corrected for the mean and contemporary group sums of squares. This statistic identifies the SNP window that explains the largest amount of variation in WBSF regardless of the number of haplotypes that are fit.

Results and discussion

We found large differences in the heritabilities of WBSF across the five breeds (Table 1) and were concerned that this might reflect differences in data quality or the correct assignment of phenotype to genotype because of the sample misidentification issue identified within the CMP. However, we also estimated heritabilities for eight additional carcass traits recorded in this project (data not shown) and found no evidence for systematically lower heritabilities within any of the breeds. We therefore conclude that the re-extraction of DNA from tissue samples taken from the carcass at slaughter effectively solved the misidentification problem. Thus, the variation in heritabilities probably reflects the relatively small sample size within each breed and the sampling of the bulls used to produce these animals. However, the effect of variation in heritability across breeds was to substantially influence the 'genetic' sample size which we estimate as $N \times h$, the number of phenotypes multiplied by the square root of the heritability, which is an estimate of the cumulative amount of additive genetic information in a sample of N unrelated individuals and was 468.3, 451.5, 471.7, 85.4 and 143.5 in Angus, Hereford, Charolais, Limousin and Simmental respectively.

In the across-breed analysis, the use of the genomic relationship matrix corrects for the stratification because of pedigree relatedness while accounting for the extent of background relatedness among the Angus and Continental breed groups because of the use of Angus dams to produce the crossbred Continental breed calves. In this analysis, the associations between the *CAST* and *CAPN1* loci with WBSF were the largest in the genome (Fig. 1), reflecting both the magnitude of effects of these genes and the increased SNP density within these regions, which improves the likelihood of finding SNP in strong LD with the causal mutations. The within-breed analyses identified *CAPN1* as the locus most strongly associated with WBSF genome-wide, although the highest ranked SNP ASE within this region for Limousin was only 30th (Table S2), presumably reflecting the very small sample size for this breed. On the other hand, the *CAST* associations were more variable among the breeds, being the most strongly associated with WBSF genome-wide in Hereford, ranking highly in Charolais and Limousin, but only 234th and 208th in Angus and Simmental respectively. These results are likely due to the fairly small sample sizes for the analysed breeds, but probably also may reflect the different SNP densities within the two regions and differences in allele frequencies at the SNPs and QTL across breeds. We accomplished a much higher SNP density in the region harbouring *CAPN1* than *CAST,* and this suggests that we had insufficient SNPs to find at least one that was in strong LD with the causal mutations within *CAST* in all breeds.

Across all 40 645 SNPs, the correlations between ASEs estimated within each of the breeds varied from −0.02 to 0.04, indicating that models developed to predict genomic breeding values within one breed will have very low accuracies in other breeds. This has previously been predicted using simulated data (de Roos *et al.* 2009; Toosi *et al.* 2010) but, despite the use of commercial Angus females to produce the Continental breed crossbred steers, it is a

consequence of the genetic distance between the training and validation sets of animals. Habier *et al.* (2010) demonstrated that the number of generations that separate the training and validation data sets influences the accuracy of genomic breeding values estimated in the validation set, with lower accuracies occurring when this relationship is more distant. On the other hand, the correlations between the ASEs estimated in the across-breed analysis and those estimated in the within-breed analyses were 0.37, 0.66, 0.41, 0.31 and 0.42 for Angus, Hereford, Charolais, Limousin and Simmental respectively. This result supports the simulation results of Toosi *et al.* (2010), who showed that training in admixed populations results in genomic estimates of breeding value with accuracies almost equivalent to those achieved from training and validating within the same breed. Of course, the key benefits from the perspective of beef cattle breeding are that training population samples can dramatically be increased by pooling breeds and that the resulting genomic breeding values have industry-wide utility.

Hayes & Goddard (2001) have estimated that between 50 and 100 QTL underlie variation in quantitative traits within livestock populations. While under neutral theory, the common QTL mutations that are detectable by GWA analysis must predate the domestication of cattle (Kimura & Ohta 1973), the relatively small populations upon which breeds were founded may have led to the sampling of different subsets of QTL within different breeds. In fact, the extent to which breeds share common QTL is unknown (Pryce *et al.* 2010), but is of some importance to the development of prediction equations for molecular estimates of breeding value in admixed populations and the development and utilization of genotyping assays for the prediction of genetic merit within the beef industry. To identify QTL underlying variation in WBSF, we examined the genomic regions harbouring the 500 SNPs with the largest ASEs from the across-breed analysis for SNPs with ASEs ranked in the top 500 in the within-breed analyses for at least three of the breeds. We identified 79 genomic regions that putatively harbour QTL influencing WBSF (Table 2). Of these, 42 were identified in three breeds, 29 in four breeds and eight in all five breeds. There was no difference between the breeds ($P = 0.48$) or between British and Continental breeds ($P = 0.52$) in the probability of QTL detection for all 79 QTL or for the 42 QTL identified in only three breeds ($P = 0.35$ and 0.82 respectively). Clearly sample size, assay SNP density, constraints on SNP ranks and the size of regions harbouring highly ranked SNP ASEs all impact the identification of putatively common QTL. Of the 113 instances when the within-breed estimated SNP ASEs ranked >500, the average rank was only 2551, suggesting that the majority of these regions harbour QTL that segregate in all breeds. Changing the minimum within-breed ASE rank criterion to <1000 resulted in 17 of these QTL being detected in all five breeds, 41 in four breeds and 21 in three breeds (Table 2). Thus, there appears to be little phylogenetic signal in these data, and if a QTL was detected in only three breeds, these breeds were as likely to be British and Continental as strictly Continental.

We have previously found poor concordance between GWA and half-sib linkage analyses for large-effect QTL underlying growth traits, even when large numbers (>50) of families with family sizes ranging from 20 to 224 half-sibs are analysed (data not shown). Assuming that GWA analysis detects common variants, we would expect a significant number of sires to be both heterozygous and detected to be segregating for a large-effect QTL; however, this largely depends on the underlying genetic architecture of the trait. Reed *et al.* (2008) found that growth was affected in 34% of viable mouse knockouts, suggesting that natural variation in thousands of genes underlies variation in growth. As a consequence of this complex genetic architecture, there may be a large number of QTL on each chromosome, and the allelic combinations present at these QTL in the sire will impact on whether any one QTL is detected in linkage analyses. Thus, common variants detected in GWA analysis may not be detected in segregation analysis, and rare variants detected in segregation analysis may not be detected in GWA analysis. Nevertheless, we found six of the 12 previously reported meat tenderness QTL, including *CAST* and *CAPN1,* to coincide with the QTL identified in this study (Table 2) (Cattle QTL database, http://www.animalgenome.org/cgi-bin/QTLdb/BT/draw_traitmap?trait_ID=1030, accessed June 27, 2011). Notwithstanding the poor resolution of QTL location mapped by linkage analysis, we also found support for all of the other previously identified QTL. For example, in the across-breed analysis, QTL were identified with ASE ranks <500 at 3 151 989 bp and at 6 831 955–7 086 105 bp (300 kb from *MSTN*) on BTA2. The first was supported by ASE ranks <500 for Angus and Charolais, but an ASE rank of 565 in Limousin. The second was supported by an ASE rank <500 in Charolais and ASE ranks <1000 in Angus, Limousin and Simmental. Thus, despite their proximity, these QTL are likely distinct, and the concordance between our and previously published results suggests that the genetic architecture of meat tenderness is substantially less complex than for growth.

We examined the genomic regions harbouring the 37 QTL that were detected in at least four of the breeds for potential candidate genes underlying meat tenderness. Very little is known about the genetic regulation of meat tenderness, and few candidate genes are suggested for these QTL. While *CAST* and *CAPN1* have consistently been identified and analysed as candidate genes for the BTA7 97 861 341–98 820 742-bp and BTA29 44 042 363–44 087 629-bp QTL, respectively, no causal variants have been identified in either gene. *CAPN1*

Table 2 Genomic regions identified as harbouring QTL that were detected in at least three breeds.

BTA	Start[1]	End[1]	SNP[2]	Location[2]	No. SNP[3]	Breeds	Angus[4]	Hereford[4]	Charolais[4]	Limousin[4]	Simmental[4]	All breeds[4]
1	27 034 490	29 073 969	*rs42409195*	28 111 487	30 (2)	C, L, S	7433	6333	37	189	19	335
1	155 725 361	156 105 357	*rs41600022*	155 725 361	8 (1)	H, L, S	2242	43	967	429	267	423
3	306 322	1 267 869	*ss86301348*	1 267 869	17 (1)	A, H, C	154	134	222	6584	3319	210
4	62 189 085	62 766 260	*rs43403458*	62 685 650	16 (2)	H, C, S	2695	244	292	1679	176	60
5	4 501 932	5 240 327	*ss86306901**	5 012 505	15 (1)	A, H, S	90	422	8827	3688	453	458
5	21 876 606	23 103 768	*rs29014779*	21 876 606	19 (1)	C, L, S	846	3002	51	441	181	444
5	99 077 991	101 271 357	*rs41654473*	101 271 357	24 (1)	C, L, S	1105	1269	83	280	270	319
6	20 730 690	22 576 164	*rs42756258*	21 884 446	36 (2)	A, C, L, S	10	2467	191	304	78	190
6	102 116 041	104 245 701	*ss117968229*	103 281 884	44 (3)	A, L, S	214	625	1463	94	48	273
7	55 116 289	57 554 684	*rs29012174*	55 116 289	36 (1)	A, H, L, S	65	132	727	105	262	47
7	73 155 944	74 367 220	*ss86318554*	74 367 220	28 (1)	A, H, C, L	358	102	470	144	3570	288
7	77 854 696	83 621 039	*rs43527386*	80 731 488	89 (3)	H, C, L, S	1478	94	420	219	424	71
7	97 861 341	98 820 742	*rs41255587**	98 579 574	19 (8)	A, H, C, L, S	237	1	14	37	308	10
7	106 927 241	108 205 624	*rs43531510*	106 927 241	24 (2)	H, C, S	8668	163	49	972	306	98
8	3 830 280	4 955 143	*rs41618019*	4 955 143	19 (1)	A, H, S	137	57	534	9307	189	296
8	43 890 714	46 946 557	*rs42312419*	43 890 714	48 (1)	H, C, L, S	3561	208	16	410	126	31
8	65 338 177	69 622 989	*ss117969253*	68 894 735	68 (4)	A, H, C, L, S	156	85	198	240	90	29
8	97 684 074	98 861 495	*ss86319219*	98 746 331	16 (1)	A, H, C, L	31	181	238	141	4390	184
8	112 287 843	113 301 368	*ss86338099*	112 824 694	28 (2)	A, C, L, S	76	1615	123	369	235	330
9	36 960 364	40 088 647	*rs41623216*	38 252 618	41 (2)	H, L, S	1224	410	1033	126	151	188
10	6 871 209	8 514 821	*ss86317616*	7 830 003	26 (1)	A, L, S	299	2813	3578	238	99	338
10	15 413 589	16 985 300	*ss86317957*	16 326 848	34 (1)	A, H, L, S	383	128	4565	486	451	113
10	29 278 086	31 692 125	*ss86305679*	29 278 086	29 (1)	A, H, L, S	162	184	896	449	293	161
10	38 799 891	40 135 969	*rs42412333*	39 278 374	18 (4)	A, H, S	222	120	4536	1974	336	211
10	96 842 358	98 541 920	*rs41590854*	97 410 796	26 (1)	A, H, L	239	415	777	113	764	262
10	102 286 251	103 234 411	*rs41596899*	102 308 122	25 (3)	H, C, L, S	3577	393	184	103	103	160
11	1 214 856	1 963 074	*ss86324631*	1 214 865	21 (1)	H, C, L, S	10476	235	469	173	107	124
11	31 734 782	33 348 373	*rs41606137*	32 224 661	26 (3)	A, L, S	288	1652	1054	336	168	241
12	35 454 037	36 764 448	*ss117970656*	35 581 416	20 (3)	H, C, S	3094	50	489	4969	211	149
12	50 715 278	52 618 243	*rs43699567*	52 573 538	40 (1)	A, H, C, L, S	416	288	385	352	27	498
13	3 723 531	5 128 166	*rs42862024*	4 308 889	22 (2)	A, H, S	107	381	3033	2879	341	305
13	29 072 163	33 201 457	*rs29011158*	31 826 409	64 (2)	A, H, C, L, S	315	242	31	36	4	151
13	66 080 035	69 702 161	*rs41631563*	66 080 035	72 (14)	A, H, C, S	471	8	61	787	142	97
13	73 369 210	73 746 516	*ss86338902*	73 746 516	9 (1)	A, H, S	344	127	594	2950	130	283
13	75 018 157	76 078 033	*ss86289318*	76 042 839	24 (2)	A, C, S	41	773	65	1767	110	43
13	80 848 032	81 665 695	*rs42630433*	81 029 787	21 (3)	A, H, C, L	386	48	69	41	5004	75
14	18 732 660	20 347 849	*rs41633333*	18 756 025	32 (5)	A, H, C	293	414	87	573	2160	76
14	47 926 524	48 572 837	*ss86299784*	48 184 967	13 (1)	C, L, S	2191	871	301	195	109	302
14	62 549 674	63 827 753	*ss86297726*	63 213 438	24 (1)	A, H, C, L	352	301	97	275	1445	166
15	31 599 942	33 310 389	*ss86291817*	32 861 621	32 (4)	A, H, L	311	31	1527	243	553	162
15	34 682 617	36 817 688	*rs41757680**	35 661 186	40 (1)	A, H, C, L, S	99	21	53	32	468	354
15	48 688 111	50 222 093	*rs41582705*	48 936 679	10 (1)	C, L, S	4718	5799	172	162	124	119
15	62 309 986	63 517 557	*rs41621125*	63 253 454	20 (1)	H, C, L	9112	77	109	444	3538	74

Table 2 (continued)

BTA	Start[1]	End[1]	SNP[2]	Location[2]	No. SNP[3]	Breeds	Angus[4]	Hereford[4]	Charolais[4]	Limousin[4]	Simmental[4]	All breeds[4]
15	64 876 840	66 717 899	*ss86314348*	64 876 840	15 (1)	H, C, L, S	1137	42	20	84	92	32
15	81 655 317	82 875 229	*ss86296417*	82 768 398	25 (1)	H, C, L	626	152	80	122	1842	178
16	11 797 915	13 358 683	*rs41623175*	12 130 589	23 (2)	A, H, C, L	18	18	4	272	1145	44
16	17 070 345	19 313 882	*ss86290236*	18 059 649	19 (1)	A, C, L, S	334	2017	256	381	96	353
16	22 147 468	23 830 920	*ss86329907*	22 406 467	17 (1)	A, H, C	401	88	354	1452	1920	216
16	25 000 153	28 384 914	*ss86291490*	27 629 566	39 (4)	H, C, L, S	1089	166	19	234	37	148
16	71 968 734	72 962 506	*rs41824081*	72 165 897	20 (2)	H, C, L	6937	265	467	55	2353	25
17	34 429 947	37 201424	*rs41626299*	34 429 947	25 (1)	H, C, L, S	1866	131	391	420	479	195
17	63 049 154	64 637 527	*ss86317522*	63 049 154	29 (1)	A, C, L, S	205	1220	347	454	391	278
17	73 315 120	74 393 620	*ss86339946*	73 315 120	27 (1)	A, C, S	166	551	361	5105	22	403
18	4 723 911	6 440 525	*ss86336538*	4 723 911	32 (1)	A, L, S	333	580	3125	151	251	83
18	55 028 139	55 621 823	*ss86310123*	55 590 144	10 (1)	A, H, S	363	418	5999	2353	28	489
20	15 870 897	17 710 059	*rs41933103*	17 175 071	35 (3)	H, C, L	1892	44	52	320	1009	36
20	64 002 006	66 587 451	*ss86335963**	66 105 424	51 (2)	A, C, L, S	142	831	273	295	261	206
21	33 764 430	34 810 865	*rs29015146*	34 165 847	19 (1)	A, H, S	378	397	2032	924	322	434
21	40 955 783	43 096 903	*rs42503056*	40 955 783	30 (1)	A, H, S	116	350	4015	2961	113	85
21	59 665 710	61 121 046	*rs41585245*	61 121 046	22 (3)	A, C, L	458	703	211	205	1790	67
21	68 152 356	68 965 986	*ss86312849*	68 846 429	17 (4)	H, C, L	2122	108	209	83	1796	33
23	48 537 019	49 094 579	*rs41617911*	48 856 081	16 (1)	A, C, L	89	2461	332	448	2831	329
25	1 160 378	2 105 645	*ss117973580*	1 919 606	21 (2)	A, L, S	215	1633	2777	387	478	116
25	14 683 151	15 752 362	*ss86336453*	15 752 362	23 92)	A, C, L, S	96	1940	306	60	145	132
25	19 762 712	22 728 704	*rs41572366*	21 655 452	47 (2)	A, H, C, L, S	97	63	495	3	258	102
25	27 545 745	30 572 524	*ss86283327**	29 485 851	48 (2)	A, H, C, L, S	57	499	99	102	68	49
26	12 580 311	14 127 433	*ss86273489*	13 293 856	27 (1)	A, H, S	27	107	4581	641	461	144
26	17 058 843	18 288 540	*ss86287439*	18 288 540	25 (2)	A, H, L, S	243	404	512	93	212	138
26	29 698 221	31 348 288	*rs41646897*	30 903 998	37 (1)	A, H, C, S	420	76	317	897	183	63
26	41 183 634	43 312 255	*ss86282954*	42 274 097	37 (2)	H, L, S	3947	23	701	256	445	388
27	3 343 936	6 388 642	*rs29024621*	3 909 806	24 (1)	A, H, L, S	275	80	2437	412	201	401
27	19 195 734	21 993 669	*rs42118878*	19 195 734	39 (4)	H, L, S	2323	323	538	192	42	35
27	34 978 041	36 054 950	*ss86310277*	35 372 600	21 (1)	A, H, C, S	304	425	149	1423	222	364
28	4 837 387	5 876 902	*rs41612729*	5 052 476	24 (3)	H, C, L, S	1466	317	438	117	233	280
28	31 700 004	34 066 383	*ss86337100*	33 570 352	33 (1)	A, H, L, S	39	138	3800	70	7	19
28	37 398 488	38 314 983	*rs29013966*	37 514 643	20 (1)	H, C, S	624	320	110	916	450	84
28	43 815 607	44 961 253	*ss86283362*	44 694 578	25 (1)	A, C, S	153	834	121	696	84	389
29	34 618 653	36 573 929	*rs29022154*	35 387 115	35 (2)	A, C, L, S	120	2258	276	35	87	129
29	44 042 363	44 087 629	*rs42192103**	44 070 713	30 (18)	A, H, C, L, S	1	4	1	30	1	1

A, Angus; C, Charolais; H, Hereford; L, Limousin; S, Simmental; QTL, quantitative trait loci; SNP, single-nucleotide polymorphism.

[1]UMD3.0 coordinates for the SNPs defining the boundaries of the SNP putatively harbouring the QTL.

[2]Identity and UMD3.0 coordinate of the most strongly associated SNP within the interval as determined in the across-breed analysis. QTL previously reported in the Cow QTL Database (http://www.animalgenome.org/cgi-bin/QTLdb/BT/draw_traitmap?trait_ID=1030) are indicated with asterisks.

[3]Number of SNPs within the interval. Number of SNPs within the region ranked in top 500 ASEs in the across-breed analysis in parentheses.

[4]Lowest rank for t_i value within the interval.

encodes the protease μ-calpain, which has been implicated in the proteolysis of muscle proteins during meat ageing (Smith *et al.* 2000), and *CAST* encodes calpastatin, which is an inhibitor of μ-calpain (Goll *et al.* 2003). Myogenic determination factor 1 is a transcription factor encoded by *MYOD1* and is expressed in skeletal muscle during myogenesis and regeneration. Variation in *MYOD1* has been suggested to affect its ability to influence the expression of muscle structural components (Rexroad *et al.* 2001), making it a candidate for the QTL at 34 682 617–36 817 688 bp on BTA15. Calpain-2 (m/II) large subunit (m-calpain) is a calcium-activated neutral protease encoded by *CAPN2* on BTA16 (25 000 153–28 384 914 bp). M-calpain activity has been associated with both meat tenderness and palatability measurements (Riley *et al.* 2003). Fibroblast growth factor 2 (*FGF2*) is an upstream regulator of heat shock protein B1 (*HSPB1*), which has been found to be negatively related to WBSF (Kim *et al.* 2011), making it a candidate for the 34 429 947–37 201 424-bp QTL on BTA17. *GSN* encodes gelsolin, a calcium-regulated protein that functions in both the assembly and disassembly of actin filaments, which are a component of the contractile apparatus in muscle cells and may underlie the BTA8 112 287 843–113 301 368-bp QTL. Finally, *CALM1* encodes calmodulin, a calcium-binding protein, which interacts with titin and mediates smooth muscle contraction, making it a candidate for the BTA10 102 286 251–103 234 411-bp QTL.

While the commercially tested *CAST* SNP *rs41255587* was the most strongly associated with WBSF in the across-breed analysis ($-\log_{10}P = 8.95$), it was only the most strongly associated *CAST* SNP within Hereford and Charolais, with stronger associations being detected for SNPs in the 5′ upstream region in Angus, Limousin and Simmental (Table S3). In fact, the haplotype analysis moves the location of the most significantly associated SNP window 83.7 kb upstream of *rs41255587* to be centred on *rs43529872* ($-\log_{10}P = 8.78$), and this *CAST* window was found to explain the greatest amount of phenotypic variation in WBSF in the across-breed (1.02%; Table 3), Angus and Hereford analyses. The sign and magnitude of the ASE was consistent for *rs41255587* in all breeds except Limousin, and the haplotype analysis explained considerably more variation in WBSF than the single SNP analysis, indicating that either the causal variant is not among the tested polymorphisms or that there is more than one causal variant. Furthermore, the haplotype analyses move the most likely location of the causal mutation 5′ of the commercially tested *CAST* SNP *rs41255587*, probably in the 678-kb region from 97 861 341–98 538 952 bp (Fig. 2). Clearly, additional fine-mapping is required to identify the number of mutations influencing WBSF that lie in the vicinity of *CAST* and their most likely locations.

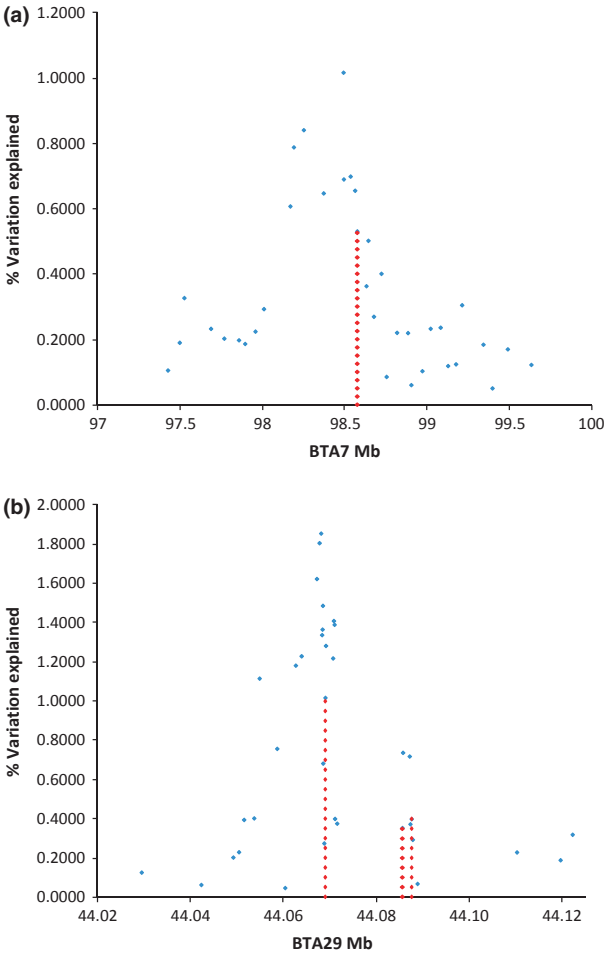

Figure 2 Proportion of phenotypic variation in the across-breed analysis explained by haplotypes constructed from nine consecutive single-nucleotide polymorphism (SNPs) in the region of (a) BTA7 harbouring *CAST* and (b) BTA29 harbouring *CAPN1*. Locations and amount of variation explained by the commercialized tenderness SNPs are indicated by red dotted lines.

Among the SNP located within *CAPN1*, *rs17812000* (c.316G>A) was most strongly associated with WBSF in Angus ($-\log_{10}P = 9.70$) and *rs17872050* was the most strongly associated with WBSF in Limousin ($-\log_{10}P = 3.23$). However, *rs42192103* was found to be slightly more strongly associated with WBSF than *rs17812000* in the across-breed analysis ($-\log_{10}P = 15.25$ vs. 15.01), with an average ASE across breeds of 0.23 kg (Table S3). The amount of phenotypic variation explained in the haplotype-based analyses again indicates that none of the tested SNPs are causal for effects on WBSF and that the strongest signal for association with WBSF was in the 8187-bp region from 44 062 694 to 44 070 881 in all five breeds (Table S3). The size of this region is sufficiently small to speculate that there is probably only a single mutation in *CAPN1* affecting WBSF in all *Bos t. taurus* cattle breeds, and the across-breed haplotype analysis shown in Table S3 and Fig. 2 suggests that the most

Table 3 Percentages of phenotypic variation in WBSF explained by the commercialized SNPs, the most strongly associated SNPs and haplotypes within the most strongly associated nine SNP window within *CAST* and *CAPN1*.

Locus	All breeds	Angus	Hereford	Charolais	Limousin	Simmental
CAST (BTA7)						
rs41255587[1]	0.66	0.53	1.47	1.14	0.70	0.02
98 579 574						
SNP[2]	0.66	0.54	1.47	1.14	2.28	1.13
	98 579 574	98 498 047	98 579 574	98 579 574	97 861 341	98 013 150
Window-P[3]	1.02	1.36	1.88	2.10	3.88	2.77
	98 495 888	98 495 888	98 566 391	98 538 952	97 501 859	97 861 341
Window-V_P[4]	1.02	1.36	1.92	2.10	4.02	2.77
	98 495 888	98 495 888	98 495 888	98 538 952	98 375 640	97 861 341
CAPN1 (BTA29)						
rs17812000[1]	1.14	2.36	0.96	1.38	0.00	3.75
44 069 063						
rs17871051[1]	0.39	1.54	0.16	0.39	0.57	1.66
44 085 642						
rs17872050[1]	0.53	0.89	0.08	1.21	2.88	1.65
44 097 629						
SNP[2]	1.16	2.36	1.62	1.57	2.88	4.65
	44 070 713	44 069 063	44 067 796	44 070 713	44 087 629	44 042 363
Window-P[3]	1.80	3.18	2.59	2.76	2.99	5.05
	44 067 796	44 068 519	44 062 694	44 070 881	44 087 356	44 067 234
Window-V_P[4]	1.85	3.19	2.59	2.76	3.52	5.35
	44 068 143	44 068 445	44 062 694	44 070 881	44 070 881	44 068 143

CAST, *calpastatin*; *CAPN1*, *calpain 1, (mu/l) large subunit*; SNP, single-nucleotide polymorphism; WBSF, Warner–Bratzler shear force.
[1]Commercialized SNP and its chromosomal coordinate.
[2]Most strongly associated SNP and its chromosomal coordinate.
[3]Most strongly associated nine SNP window centred on SNP with shown chromosomal coordinate.
[4]Nine SNP window explaining the greatest amount of phenotypic variation in WBSF.

likely region harbouring this mutation is the 4581-bp region from 44 063 938 to 44 068 519. This region is wholly contained within the 5′ end of *CAPN1*. We estimate from the haplotype analysis that *CAPN1* explains 1.85% of the phenotypic variation in WBSF in taurine cattle (Table 3).

Conclusions

We conclusively demonstrate that none of the SNPs currently commercialized as diagnostics for genetic merit are causal for their effects on WBSF (Casas *et al.* 2003, 2006; Van Eenennaam *et al.* 2007; Gill *et al.* 2009). In fact, the complex patterns of LD in the vicinity of these genes among the different breeds (Figs S2 and S3) and the weaker associations in Limousin and Simmental (Fig. S1) result in different SNPs being most strongly associated with WBSF among the breeds (Table S3). However, by using haplotype-based analysis methods to dissect the variation within these genes, we localized the causal variants to be 5′ to the commercially tested SNPs. In the case of *CAPN1*, the higher SNP density achieved and the use of across-breed analysis, which erodes the patterns of LD within breeds, resolved the likely location of the causal variant to a region of only 4581 bp.

We found evidence for a large number of QTL underlying variation in WBSF, and the majority of the previously published QTL were validated in this analysis. We found reasonably strong evidence that most QTL were segregating in all five breeds; however, the small genetic sample sizes for Limousin and Simmental make this comparison problematic, and it remains an unanswered question as to the extent to which breeds may share private alleles at QTL. This has previously been found in Belgian Blue, Marchigiana and Piedmontese cattle, where breed-specific polymorphisms in *MSTN* produce the double muscled phenotype (Grobet *et al.* 1997; Kambadur *et al.* 1997; McPherron & Lee 1997; Marchitelli *et al.* 2003). This issue is of importance to the development of prediction equations for molecular breeding values in across-breed analyses, because the ASEs estimated for QTL regions will be averaged across breeds that segregate and those that do not segregate for certain QTL, which will limit the accuracy of molecular estimates of breeding value. Despite this, we found moderate correlations between GBLUP predictions of ASEs computed in the across- and within-breed analyses, suggesting that the BovineSNP50 assay has sufficient resolution for the development of prediction equations for genomic selection in beef cattle despite their considerably larger effective population size relative to

dairy cattle (The Bovine HapMap Consortium 2009), and also that WBSF QTL are commonly shared among breeds.

Despite the apparent reduced complexity of a trait such as meat tenderness relative to growth, there appear to be a large number of QTL underlying variation in WBSF, and the identification of all of the mutations that underlie these QTL might appear to be intractable. However, recent developments in high-density SNP genotyping, high-throughput sequencing and genotype imputation suggest new strategies for the rapid simultaneous identification of variants underlying quantitative traits genome-wide. We accomplished an average SNP spacing of 1139 bp for the 23 SNPs analysed within *CAPN1*, and this is only slightly smaller than could be accomplished genome-wide by jointly genotyping with the newly available Illumina BovineHD and Affymetrix BOS 1 assays (~1.3 million SNP, data not shown). Furthermore, the design of these assays was facilitated by a community effort that produced more than 128.4X of genome sequence coverage on more than 80 animals, and SNP data from this work are now available in dbSNP. This project discovered 48.6 million high-quality SNPs, which must include many of the causal variants underlying quantitative variation in cattle, and it may be possible to impute genotypes at the resolution of the genome sequence (Daetwyler *et al.* 2011) in populations that have been genotyped with both assays. Such a strategy could rapidly allow the identification of a large number of causal variants if the association analysis was performed in mixed breed populations.

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Supporting information

Additional supporting information may be found in the online version of this article.

Figure S1 Manhattan plots of normalized single-nucleotide polymorphism allele substitution effects for each breed.

Figure S2 Linkage disequilibrium (LD) plots (r^2) created in HAPLOVIEW v4.1 for 44 single-nucleotide polymorphisms spanning 2.86 Mb centred on *calpastatin* on BTA7.

Figure S3 Linkage disequilibrium (LD) plots (r^2) created in HAPLOVIEW v4.1 for the 100 single-nucleotide polymorphisms spanning 3.12 Mb centred on *CAPN1* on BTA29.

Table S1 Characteristics of single-nucleotide polymorphisms located near *calpastatin* and *calpain 1, (mu/I) large subunit* that were designed into the Illumina GoldenGate assay and genotyped in 3240 CMP animals.

Table S2 Standardized single-nucleotide polymorphism allele substitution effects, within-breed *t*-like statistic ranks, heterozygosity, allele frequency and sliding window rank information.

Table S3 Patterns of single-nucleotide polymorphism association with Warner–Bratzler shear force for *calpastatin* and *calpain 1, (mu/I) large subunit* loci.

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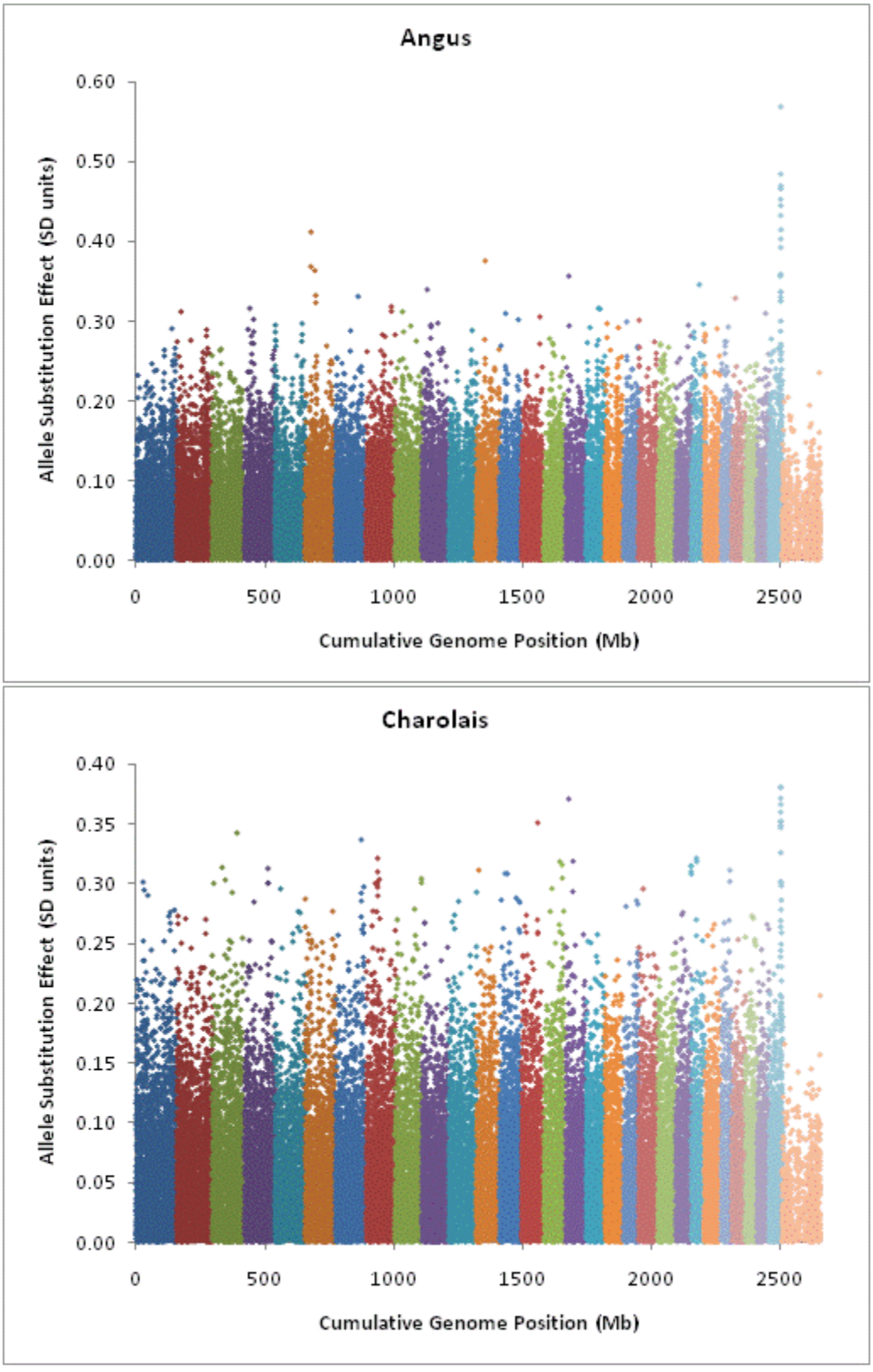
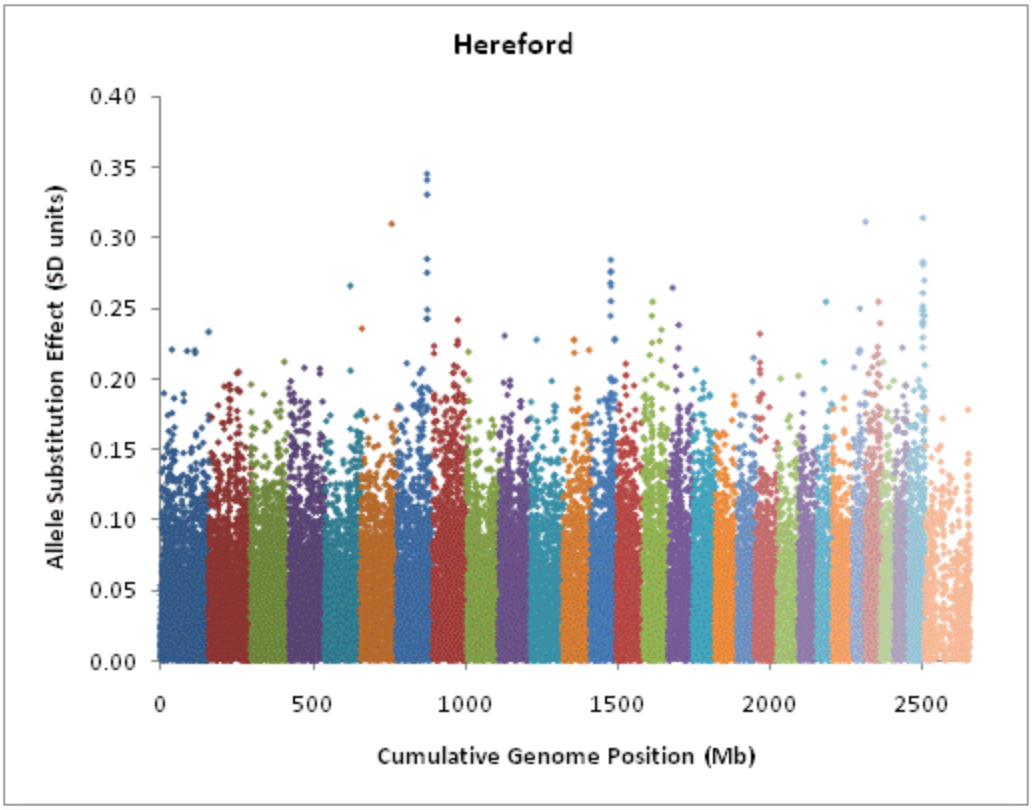
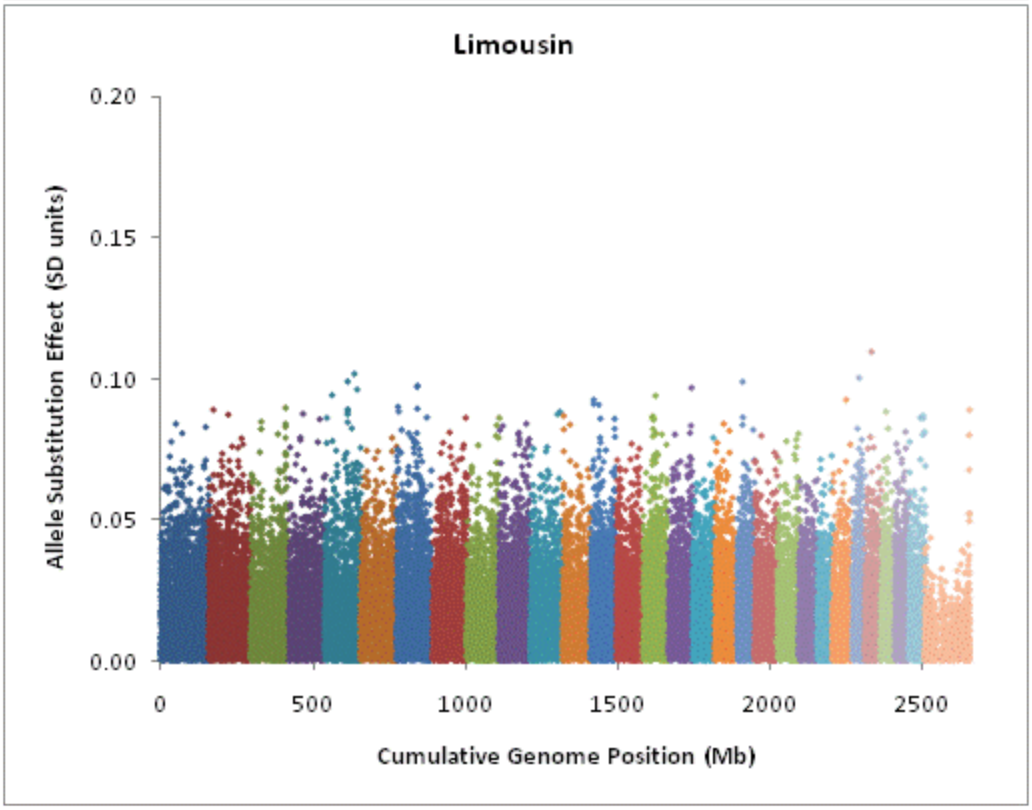
Figure S1. Manhattan plots of normalized SNP allele substitution effects for each breed.




Hereford
Allele Substitution Effect (SD units)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
500
1000
1500
2000
2500
Cumulative Genome Position (Mb)


Limousin
Allele Substitution Effect (SD units)
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0.15
0.10
0.05
0.00
0
500
1000
1500
2000
2500
Cumulative Genome Position (Mb)

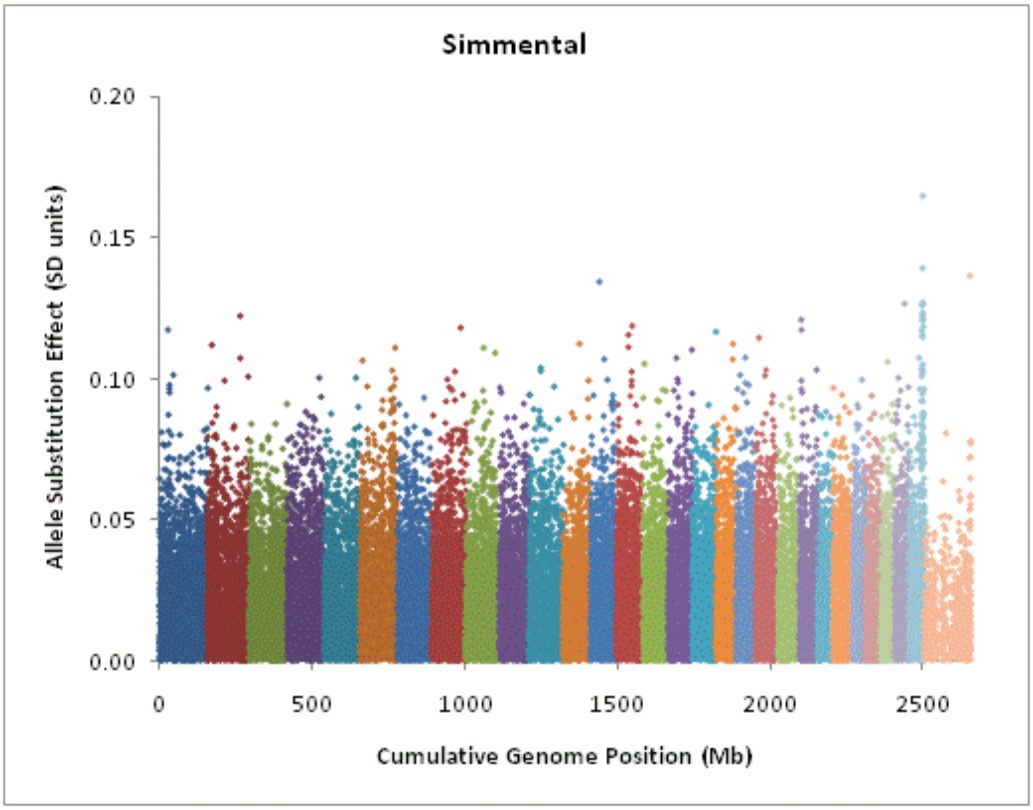
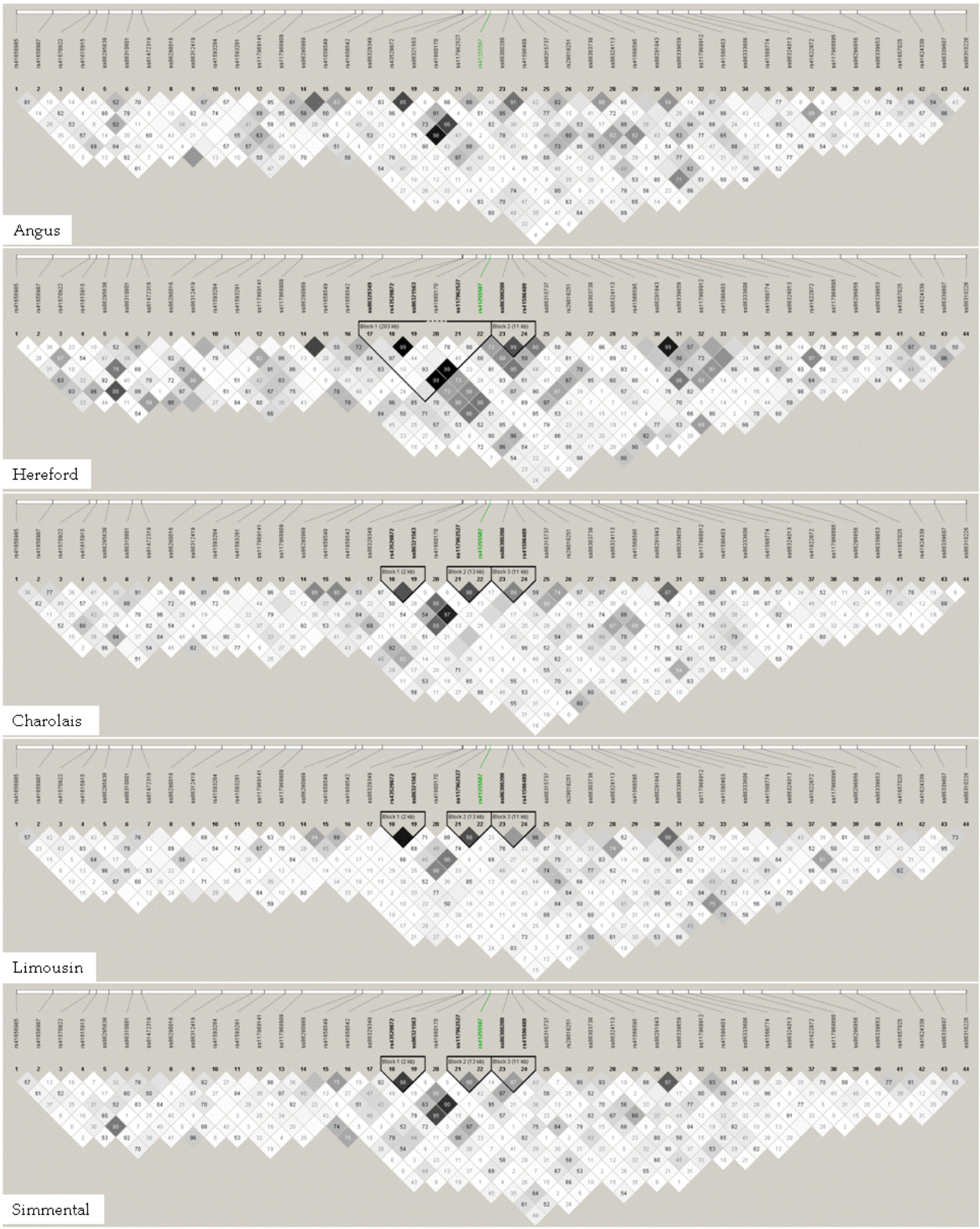

Simmental
Allele Substitution Effect (SD units)
0.20
0.15
0.10
0.05
0.00
0
500
1000
1500
2000
2500
Cumulative Genome Position (Mb)

Figure S2 Linkage disequilibrium (LD) plots (r^2) created in Haploview v4.1 (Barrett *et al*. 2005) for 44 SNP spanning 2.86 Mb centered on *CAST* on BTA7. Darker shading indicates regions of higher LD. The commercially tested SNP, *rs41255587*, (#22) is highlighted in green.



References

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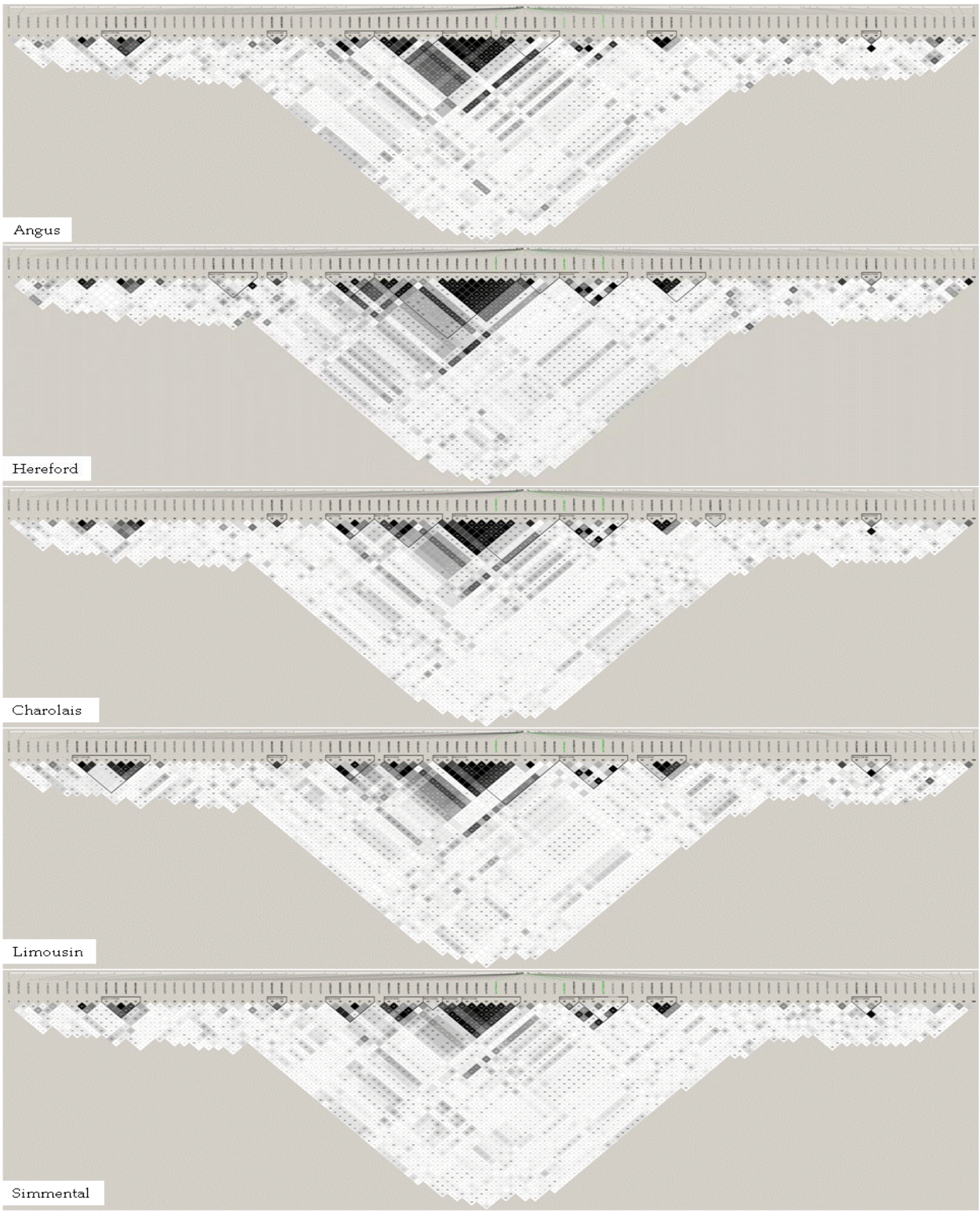
Figure S3 Linkage disequilibrium (LD) plots (r^2) created in Haploview v4.1 (Barrett *et al*. 2005) for the 100 SNP spanning 3.12 Mb centered on *CAPN1* on BTA29. Darker shading indicates regions of higher LD. The commercially tested SNP, *rs17812000* (#51), *rs17871051* (#58), and *rs17872050* (#62) are highlighted in green.



References

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Table S1 Characteristics of SNPs located near *CAST* and *CAPN1* that were designed into the Illumina GoldenGate assay and genotyped in 3,240 CMP animals

				Call Rate (%)					*A* Allele Frequency				
SNP ID[1]	BTA	POS[2]	Filtered[3]	Angus	Hereford	Charolais	Limousin	Simmental	Angus	Hereford	Charolais	Limousin	Simmental
rs42269174	7	98,260,103	AF	99.09	98.41	99.00	89.47	97.89	0.0000	0.0009	0.0000	0.0000	0.0000
rs42269169	7	98,346,128	AF	99.09	97.82	99.00	89.12	97.50	1.0000	0.9991	1.0000	0.9980	0.9990
rs42269168	7	98,351,749	CR,AF	93.48	92.03	96.58	88.42	95.20	0.9749	0.9699	0.9904	0.9782	0.9808
rs42269166	7	98,381,155	AF	98.79	97.57	99.00	90.18	97.89	0.0000	0.0000	0.0000	0.0039	0.0000
rs42269167	7	98,406,957	AF	98.64	96.90	99.15	91.23	98.46	0.0077	0.0074	0.0101	0.0058	0.0058
rs42269164	7	98,414,333	CR,AF	98.94	96.81	97.72	88.42	96.93	0.9985	0.9931	0.9942	0.9940	0.9851
rs42269165	7	98,423,052	CR,AF	98.94	97.57	98.72	88.77	97.70	0.0000	0.0000	0.0000	0.0000	0.0000
rs43529864	7	98,446,203	AF	98.94	97.57	98.86	89.82	97.89	0.0000	0.0000	0.0000	0.0000	0.0000
rs43529865	7	98,447,598	AF	98.64	97.06	99.00	89.12	97.31	1.0000	1.0000	1.0000	1.0000	1.0000
rs43529866	7	98,450,896	AF	99.24	98.57	99.15	89.82	97.89	1.0000	0.9991	1.0000	1.0000	1.0000
rs43529867	7	98,462,790	AF	99.09	98.07	98.86	90.18	98.27	0.0000	0.0000	0.0000	0.0000	0.0010
rs43529868	7	98,465,338	AF	98.94	97.48	98.29	89.12	97.89	1.0000	0.9991	1.0000	1.0000	0.9980
rs41596484	7	98,481,587	AF	99.09	97.90	98.86	89.82	97.50	0.0122	0.0043	0.0677	0.0137	0.0600
rs41596488	7	98,482,088	CR	99.09	97.32	98.43	88.77	97.31	0.7768	0.4767	0.7359	0.8241	0.5592
rs43529869	7	98,486,784	AF	98.18	97.06	98.72	90.18	97.12	0.0000	0.0000	0.0000	0.0000	0.0000
rs43529872	7	98,495,888		99.09	98.15	98.72	90.18	98.08	0.2064	0.5094	0.1912	0.1518	0.3630
rs43529870	7	98,503,071	CR,AF	95.15	77.10	93.02	89.82	84.84	0.9968	0.9717	0.9931	0.9961	0.9706
rs41619071	7	98,601,495	DNC										
rs43529862	7	98,525,723	AF	99.24	98.24	98.58	89.82	97.70	0.9992	0.9983	0.9993	1.0000	0.9951
rs41660170	7	98,538,952		99.09	97.06	99.15	90.18	98.08	0.0749	0.0402	0.1121	0.0856	0.0646
rs42776088	7	98,559,498	AF	99.09	95.72	98.86	89.82	97.50	1.0000	0.9982	1.0000	1.0000	0.9990
rs42776087	7	98,574,830	CR	98.94	96.73	98.29	88.77	96.35	0.2213	0.5108	0.2471	0.2688	0.4373
rs41255587	7	98,579,574		98.64	96.31	98.01	89.47	96.55	0.2166	0.5109	0.2406	0.2725	0.4205
rs42776090	7	98,620,447	AF	99.24	98.49	99.00	89.82	98.08	1.0000	0.9991	1.0000	0.9980	0.9980
rs41596489	7	98,646,770		99.24	98.15	98.72	89.12	97.70	0.4901	0.6970	0.6154	0.7756	0.6916
rs43529875	7	98,680,392	AF	99.09	98.07	98.58	89.12	98.46	1.0000	0.9987	1.0000	1.0000	0.9951
rs43529877	7	98,701,638	AF	99.24	98.57	99.15	89.82	98.27	0.0023	0.0060	0.0036	0.0059	0.0020
rs41657006	7	98,709,304	CR	93.94	78.69	85.33	85.61	55.09	0.3750	0.2655	0.3038	0.2111	0.2648
rs43101783	29	43,924,518	AF	98.79	97.65	97.72	89.47	96.93	0.9969	0.9987	0.9942	0.9902	0.9990
rs42191319	29	44,000,728		98.64	96.81	98.72	90.88	97.50	0.0630	0.2959	0.0938	0.0946	0.1358

rs42192038	29	44,029,526		98.33	97.99	98.58	89.47	97.31		0.4923	0.5801	0.3736	0.2137	0.3481
rs42192064	29	44,042,363		99.09	98.15	99.00	89.47	98.27		0.6284	0.4526	0.4187	0.3902	0.4014
rs42192074	29	44,047,246	CR	98.18	96.73	97.44	88.77	95.59		0.6420	0.6019	0.6235	0.5929	0.6235
rs42192077	29	44,049,244		98.64	97.48	98.29	89.12	97.50		0.3510	0.3972	0.3652	0.3878	0.3376
rs42192079	29	44,051,567		98.33	96.56	98.15	89.82	97.31		0.6456	0.6012	0.6277	0.5938	0.6282
rs42192083	29	44,053,733		99.24	97.57	97.72	90.18	96.93		0.3573	0.4015	0.3754	0.4027	0.3663
rs42192084	29	44,054,901		98.94	96.90	98.15	89.12	95.20		0.7940	0.7290	0.7736	0.7539	0.8115
rs41596485	29	44,054,902	CR	9.09	5.03	8.55	12.98	4.99		0.5000	0.4917	0.5000	0.4865	0.5000
rs42192090	29	44,058,688		98.79	98.15	99.00	89.47	98.08		0.4410	0.5679	0.4626	0.6412	0.4374
rs42192096	29	44,060,410		99.24	97.82	98.86	90.18	98.08		0.5534	0.4125	0.4697	0.2899	0.5548
rs42192100	29	44,062,694		98.79	97.23	98.01	89.82	96.74		0.5529	0.4142	0.4731	0.2910	0.5595
rs17872077	29	44,063,844	CR	87.12	84.90	91.03	79.30	85.99		0.1122	0.1260	0.0845	0.0664	0.0993
rs41657009	29	44,063,937	DNC							0.0000	0.0000	0.0000	0.0000	0.0000
rs17872078	29	44,063,938		98.94	96.98	98.72	90.18	97.70		0.4893	0.2171	0.3333	0.1868	0.3536
rs17872101	29	44,066,634	AF	99.09	98.49	99.00	90.18	98.46		0.0000	0.0000	0.0000	0.0000	0.0000
rs17871028	29	44,067,079	AF	99.24	96.98	98.86	89.82	97.31		0.0031	0.0078	0.0029	0.0000	0.0286
rs17872081	29	44,067,161	AF	98.48	97.90	98.43	89.82	97.89		0.0000	0.0004	0.0000	0.0000	0.0020
rs17872093	29	44,067,234		99.24	97.48	97.72	89.82	97.31		0.4466	0.5856	0.5313	0.7090	0.4438
rs17872094	29	44,067,596	CR	62.27	56.71	73.36	49.47	69.10		0.3917	0.6198	0.5427	0.4681	0.6153
rs17871984	29	44,067,796		99.24	97.65	98.58	90.18	98.46		0.1260	0.2302	0.2406	0.1498	0.3343
rs17870633	29	44,067,919	AF	98.94	98.07	98.86	90.18	97.31		0.0000	0.0004	0.0007	0.0000	0.0020
rs17871987	29	44,067,984	CR	99.24	97.73	98.72	88.77	97.50		0.4267	0.1833	0.2302	0.1403	0.2185
rs17870631	29	44,068,143		99.24	97.99	98.72	90.53	98.08		0.5725	0.8134	0.7691	0.8566	0.7789
rs17870630	29	44,068,247	AF	99.24	98.24	98.58	90.18	97.89		1.0000	0.9996	1.0000	1.0000	1.0000
rs17870628	29	44,068,346		98.94	97.48	98.01	89.47	97.89		0.5352	0.8081	0.7071	0.7902	0.7010
rs17870626	29	44,068,445		99.09	97.82	98.72	90.18	96.55		0.5680	0.8135	0.7655	0.8521	0.7465
rs17872010	29	44,068,519		98.94	97.23	97.72	90.18	97.31		0.5743	0.8162	0.7682	0.8560	0.7761
rs17872004	29	44,068,580		98.33	97.40	98.29	90.18	95.97		0.5732	0.8178	0.7703	0.8541	0.7820
rs17872003	29	44,068,812		97.58	96.39	98.15	89.82	96.93		0.4278	0.1819	0.2315	0.1445	0.2188
rs17872000	29	44,069,063		98.18	95.72	99.43	99.30	99.23						
rs17872006	29	44,069,177		96.21	97.23	97.86	89.47	97.12		0.4299	0.1877	0.2394	0.1451	0.2322
rs42192102	29	44,070,590	CR	98.79	97.23	98.15	87.72	97.70		0.4371	0.5669	0.5203	0.6860	0.3978
rs42192103	29	44,070,713		96.67	95.81	98.29	89.82	96.55		0.4326	0.1988	0.2355	0.1641	0.2674
rs42192105	29	44,070,881		98.79	97.57	97.72	89.47	97.31		0.1304	0.1561	0.0707	0.0431	0.0966

rs42192107	29	44,071,034		98.94	97.48	98.72	90.53	97.70		0.1187	0.1506	0.0592	0.0426	0.0452
rs42192108	29	44,071,135		99.09	97.32	98.43	89.82	97.70		0.0344	0.1858	0.1606	0.0781	0.0472
rs42192109	29	44,071,593		98.79	96.90	98.58	89.47	97.31		0.4954	0.3935	0.3728	0.2667	0.4043
rs42192110	29	44,071,657	CR	99.24	97.65	98.15	88.42	97.89		0.5595	0.4214	0.4768	0.3056	0.5500
rs42192111	29	44,071,828	CR,AF	74.24	63.17	60.97	44.91	63.34		1.0000	0.9967	1.0000	0.9844	0.9970
rs42192117	29	44,081,264	AF	98.18	97.23	98.86	89.82	97.50		0.0000	0.0000	0.0000	0.0000	0.0010
rs17870499	29	44,085,195	CR	98.64	97.40	98.58	88.07	97.70		0.0499	0.0263	0.0874	0.1096	0.0697
rs17871051	29	44,085,642		99.39	97.65	98.29	89.12	97.50		0.0998	0.1044	0.3659	0.3996	0.3051
rs17871058	29	44,085,769	DNC*											
rs17871060	29	44,086,042	AF	99.24	98.07	98.29	89.82	96.55		1.0000	1.0000	1.0000	0.9961	1.0000
rs17872027	29	44,086,761	AF	99.24	97.82	99.00	90.53	97.89		0.0061	0.1677	0.0259	0.0174	0.0216
rs17872030	29	44,086,943	CR	98.64	97.40	98.29	88.42	96.35		0.0975	0.1047	0.3616	0.4028	0.3058
rs17872031	29	44,087,019	AF	94.70	97.82	96.58	90.53	98.27		0.0160	0.0262	0.0133	0.0000	0.0078
rs17872032	29	44,087,205		98.33	97.32	98.15	90.18	96.93		0.0493	0.0250	0.0842	0.0953	0.0683
rs17872033	29	44,087,356		97.58	96.31	97.58	89.82	95.39		0.8960	0.8916	0.6263	0.5938	0.6620
rs17872050	29	44,087,629		99.55	96.64	99.29	99.65	99.04						
rs17872151	29	44,087,858		99.09	97.90	98.15	90.18	97.70		0.0153	0.0167	0.0856	0.1323	0.0452
rs17872153	29	44,088,027	CR	99.09	97.65	98.01	87.72	96.93		0.9893	0.9854	0.8990	0.8360	0.9010
rs17870855	29	44,088,451	CR	98.79	97.15	98.43	88.77	96.93		0.0997	0.1036	0.3647	0.4071	0.3267
rs17870847	29	44,088,897		99.24	97.23	98.72	90.53	98.08		0.7038	0.8352	0.4531	0.3217	0.5284
rs17870848	29	44,089,043	CR	88.94	91.78	91.31	81.05	91.55		0.6457	0.5457	0.6131	0.5714	0.5461
rs42192119	29	44,110,295		99.24	98.24	98.86	89.82	98.08		0.3267	0.4539	0.4150	0.4219	0.3591
rs42192125	29	44,112,272	AF	99.09	97.73	99.15	90.88	98.46		0.0000	0.0000	0.0000	0.0019	0.0010
rs42195143	29	44,119,671		96.82	96.31	98.29	90.18	96.35		0.5939	0.6224	0.6203	0.5233	0.6365
rs42194216	29	44,122,272		99.09	98.07	98.86	89.82	97.70		0.0956	0.1737	0.0620	0.1543	0.1130
rs42194178	29	44,125,747		99.55	98.07	98.86	90.88	97.89		0.0951	0.1698	0.0641	0.1544	0.1118
rs42194132	29	44,130,887		99.09	97.15	99.15	89.12	97.70		0.9060	0.8286	0.9368	0.8465	0.8870
rs42193349	29	44,154,126		98.18	97.32	98.01	89.12	97.50		0.0332	0.1586	0.0334	0.1240	0.0827
rs42193335	29	44,163,955	AF	99.09	97.99	98.72	89.82	97.31		1.0000	0.9991	1.0000	0.9961	1.0000
rs41586223	29	44,196,154	DNC											
rs29003633	29	44,208,978		98.94	97.99	99.00	90.18	97.89		0.0398	0.0424	0.0540	0.0136	0.0480
rs42195220	29	44,235,914	AF	99.24	98.49	99.15	90.53	98.27		0.0000	0.0000	0.0000	0.0000	0.0000

[1]Identities of commercialized SNPs predictive of tenderness are shaded in red. Identities of SNPs within *CAST* and *CAPN1* are shaded in yellow.

Bold SNPs have been removed from dbSNP.

[2]Base pair position from the UMD3.1 sequence assembly.									
[3]Reason for filtering SNP from analysis. DNC=Did not convert, AF=Allele Frequency, CR=Call rate. * = Also included on BovineSNP50 assay.									

Table S3. Patterns of SNP association with WBSF for *CAST* and *CAPN1* loci.

					Rank[3]			
BTA	POS[1]	SNP ID[2]	All Breeds	Angus	Hereford	Charolais	Limousin	Simmental
7	97,151,592	*rs41656985*	17853	22832	22123	11997	40460	19009
7	97,261,052	*rs41656987*	654	5620	39476	13999	1891	2069
7	97,372,656	*rs41570922*	20417	16753	26124	38433	14071	33362
7	97,393,157	*rs41615915*	1427	37659	39656	1009	17193	6660
7	97,430,691	*ss86295638*	3045	39136	27527	1047	23654	13621
7	97,501,859	*ss86310801*	13413	33096	22602	19582	10997	16395
7	97,529,872	*ss61472319*	10706	16140	20625	1743	6464	29536
7	97,691,853	*ss86290016*	30824	31090	22986	36148	36108	24197
7	97,772,240	*ss86312419*	10263	8991	28755	7170	16285	37994
7	97,861,341	*rs41593284*	921	27589	4833	32544	37	17064
7	97,898,940	*rs41593281*	50	10852	33	23180	32882	6820
7	97,961,659	*ss117969141*	28454	25196	38529	39653	37599	25297
7	98,013,150	*ss117968909*	35590	29216	1170	4574	26692	308
7	98,173,299	*ss86290989*	30594	29793	9717	4845	29926	29007
7	98,194,828	*rs41658549*	34336	6424	2534	90	30247	15824
7	98,254,815	*rs41658542*	13991	24584	267	603	11619	21439
7	98,375,640	*ss86329349*	1790	4605	1593	38596	23512	33940
7	98,495,888	*rs43529872*	13	610	3	57	3069	20634
7	98,498,047	*ss86321563*	12	294	2	66	6102	15068
7	98,538,952	*rs41660170*	8319	6163	39936	10548	29756	20353
7	98,566,391	*ss117962527*	1310	2288	27900	619	20424	39851
7	98,579,574	*rs41255587*	10	237	1	14	2479	27896
7	98,635,208	*ss86300200*	37	11749	7	11342	4871	8383
7	98,646,770	*rs41596489*	34	628	11	38675	17319	30575
7	98,680,293	*ss86315737*	250	465	34	18680	14562	39284
7	98,726,055	*rs29018251*	13126	848	5956	5486	38597	28483
7	98,757,265	*ss86303738*	17394	26602	27914	20844	34152	5174
7	98,820,742	*ss86324113*	137	746	150	29169	22220	2224
7	98,887,313	*rs41568595*	15241	35496	29107	8018	38017	32238
7	98,907,404	*ss86291843*	9022	39450	9020	20771	4773	22927
7	98,974,456	*ss86339659*	7758	16220	6313	25941	24786	34105
7	99,024,444	*ss117968912*	24262	20693	6213	1798	15823	13240
7	99,085,299	*rs41590403*	9428	20682	24941	9134	4854	30656
7	99,130,598	*ss86333606*	1878	35186	26	34124	33105	11400
7	99,178,748	*rs41568774*	33934	35119	17840	37290	16533	18785
7	99,215,474	*ss86324013*	5728	38209	1565	37408	34561	25708
7	99,344,820	*rs41622872*	1488	20805	292	22465	1993	7618
7	99,399,852	*ss117968895*	37103	18064	39777	21174	35095	37490
7	99,492,904	*ss86296856*	6124	5452	40099	5651	36078	36085
7	99,635,841	*ss86339853*	32326	35802	7339	10001	11279	8481
7	99,687,614	*rs41657025*	19734	6764	15594	21139	38911	6044
7	99,845,133	*rs41624339*	1593	28933	13874	1849	16503	9618
7	99,919,908	*ss86339607*	35826	32733	12431	40446	13228	18950
7	100,015,468	*ss86310226*	27936	27227	9309	36010	12692	15892
29	42,406,544	*ss86319674*	37050	4925	23582	28260	21027	18936
29	42,455,680	*ss117974470*	22297	37162	29770	25573	5930	7326
29	42,620,218	*rs42189770*	35226	28646	8272	20924	33490	30054
29	42,651,294	*rs43706142*	28368	1526	13688	20292	33318	33867
29	42,696,595	*rs42189112*	11135	4128	567	12339	38243	4930
29	42,749,808	*rs29020063*	28224	13151	2449	29252	12285	1538
29	42,842,353	*ss117974486*	8500	5777	7774	25144	6122	24
29	42,897,144	*ss86322358*	27082	14890	31939	27607	33377	7184

29	43,006,000	*ss86339964*	32865	10952	32290	27608	33378	10290
29	43,043,207	*ss86341572*	20145	5329	32350	4763	12546	3676
29	43,108,445	*ss86337140*	608	1800	3230	19455	27355	8204
29	43,129,250	*ss86337549*	7614	933	38609	37467	9721	22158
29	43,189,370	*ss86319044*	9896	929	38610	39410	15557	22159
29	43,224,753	*rs29013208*	9469	1268	37486	27816	15836	8935
29	43,269,744	*ss86282762*	16588	2397	36965	25543	21052	24438
29	43,304,256	*rs29024708*	5161	1726	19477	22317	32243	344
29	43,328,607	*ss86295061*	35423	2869	9694	11234	25778	26570
29	43,429,511	*ss86318094*	42	66	37	20269	10690	7322
29	43,466,342	*ss86310741*	7210	889	20819	12113	6737	11755
29	43,498,073	*ss86338800*	1179	1059	26456	1057	12237	4447
29	43,611,640	*ss86298040*	77	13108	2175	227	27133	175
29	43,652,252	*ss86327310*	309	28	6692	33574	14789	1316
29	43,686,401	*ss86325323*	30559	1290	10319	11271	38311	16973
29	43,709,769	*ss86290081*	6403	191	4662	9805	15489	17693
29	43,747,765	*rs42190085*	9036	19561	38491	8579	26434	27476
29	43,749,527	*ss86299346*	25366	23606	37713	17640	33965	21036
29	43,777,249	*ss86299989*	35438	2116	35762	18707	39614	29763
29	43,826,144	*rs42191289*	31815	3320	9684	22649	7809	192
29	43,839,783	*ss86336460*	5396	729	9980	6073	17672	49
29	43,914,923	*ss86335514*	24	6410	3157	114	8553	102
29	44,000,728	*rs42191319*	22471	40614	11851	25045	22311	31987
29	44,029,526	*rs42192038*	1251	6182	24398	4384	19663	609
29	44,042,363	*rs42192064*	21	182	3321	11547	31563	1
29	44,049,244	*rs42192077*	8485	17117	1831	29917	40623	33046
29	44,050,471	*ss86284058*	3336	26458	559	8623	33356	13451
29	44,051,567	*rs42192079*	11270	22597	2795	29554	39615	31917
29	44,053,733	*rs42192083*	12323	17992	2555	32354	36798	30606
29	44,054,901	*rs42192084*	22522	24469	12212	13490	30189	18346
29	44,058,688	*rs42192090*	6685	2065	17751	201	10644	9852
29	44,060,410	*rs42192096*	7985	1898	10671	887	17953	3893
29	44,062,694	*rs42192100*	8555	1844	10835	1333	20163	4552
29	44,063,938	*rs17872078*	8	12	36	15	29894	25
29	44,067,234	*rs17872093*	10292	1899	6796	888	20164	3580
29	44,067,796	*rs17871984*	11	44	4	2066	19038	516
29	44,068,143	*rs17870631*	2	4	24	7	39018	6
29	44,068,346	*rs17870628*	14	16	19	750	22524	269
29	44,068,445	*rs17870626*	6	7	29	12	31903	5
29	44,068,519	*rs17872010*	7	6	40	8	39019	13
29	44,068,580	*rs17872004*	4	5	27	11	36321	9
29	44,068,812	*rs17872003*	5	3	28	6	35508	12
29	44,069,063	*rs17812000*	3	1	59	9	39020	10
29	44,069,177	*rs17872006*	9	2	46	40	24824	14
29	44,070,713	*rs42192103*	1	8	9	1	25633	2
29	44,070,881	*rs42192105*	394	6164	200	30967	37715	10226
29	44,071,034	*rs42192107*	495	5948	183	22528	37716	21810
29	44,071,135	*rs42192108*	10891	35181	23330	21578	9516	38169
29	44,071,593	*rs42192109*	1089	193	26124	100	11867	2864
29	44,085,642	*rs17871051*	22	22	8993	829	3823	128
29	44,085,769	*rs17871058*	16	29	10865	5	82	44
29	44,087,205	*rs17872032*	977	3035	36234	2335	14676	3236
29	44,087,356	*rs17872033*	27	26	9090	1020	2073	337
29	44,087,629	*rs17872050*	15	17	11193	3	30	54
29	44,087,858	*rs17872151*	7794	38670	21318	12661	22722	19232

29	44,088,897	*rs17870847*	17	23	13127	2	39	91
29	44,110,295	*rs42192119*	24761	30393	34998	11139	17791	29587
29	44,119,671	*rs42195143*	27184	13786	2181	33844	29050	24476
29	44,122,272	*rs42194216*	17667	28444	8083	27006	31593	40203
29	44,125,747	*rs42194178*	16874	25410	6562	27074	31594	40204
29	44,130,887	*rs42194132*	20944	25411	7613	26871	31592	31199
29	44,154,126	*rs42193349*	13422	10208	5641	31876	28607	21748
29	44,172,614	*ss117965984*	3742	39565	4851	10280	24312	5842
29	44,196,154	*ss86318958*	29029	13994	8832	22414	34749	33087
29	44,208,978	*rs29003633*	19817	1795	39702	33937	39148	28356
29	44,223,148	*ss86323783*	1050	105	36704	940	9476	28615
29	44,243,444	*ss86313099*	32174	543	399	4467	31547	19210
29	44,325,408	*ss86292140*	41	11	14276	2309	15992	648
29	44,372,611	*ss86329852*	15417	38369	20426	2699	9819	8295
29	44,395,075	*ss86333994*	275	979	2714	33693	22902	210
29	44,416,282	*rs43709648*	18	149	10	1683	32992	14042
29	44,546,564	*ss86288185*	494	1548	1310	4321	35230	12565
29	44,585,782	*ss86341172*	2967	2916	9784	1728	16607	18099
29	44,628,137	*rs41600300*	35992	11176	30882	26481	13878	19086
29	44,649,908	*ss86337530*	36291	30728	2567	18016	29243	4361
29	44,740,917	*ss86334185*	2424	652	2681	15788	26662	24049
29	44,807,928	*ss117965824*	20185	804	1305	37934	36739	26103
29	44,853,970	*rs42192429*	36290	112	19416	4118	21464	2705
29	44,900,940	*rs43706228*	1504	9	26793	43	35156	24021
29	44,969,518	*ss86337154*	21170	31013	35635	16801	23994	26608
29	44,979,377	*ss86338214*	24112	9928	13777	19335	30736	9711
29	44,999,264	*ss86310727*	143	1078	32294	2467	2164	425
29	45,023,665	*ss86338763*	25485	31014	30793	17900	23995	28945
29	45,102,557	*ss86332221*	170	2240	31730	75	31673	264
29	45,129,099	*ss86335405*	4960	2025	26978	5490	33645	24448
29	45,187,114	*ss86295760*	9892	468	16200	33586	24838	32136
29	45,287,502	*ss86312485*	7710	6287	36387	1294	30142	35470
29	45,326,585	*rs42198683*	23963	15047	6206	174	30801	14249
29	45,367,095	*ss86322638*	13328	12392	3940	22784	19051	6856
29	45,458,280	*rs43706176*	24499	6324	34840	34884	24588	40236
29	45,482,143	*rs29025626*	1893	136	35054	17005	2280	16790
29	45,530,264	*ss86341375*	34109	39453	35889	20334	18804	24973

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genom

[6]-$\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum va

[7]-$\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Ma

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN*

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identifie

						ASE[4]		
BTA	POS[1]	SNP ID[2]	α-All Breeds	α-Angus	α-Hereford	α-Charolais	α-Limousin	α-Simmental
7	97,151,592	*rs41656985*	0.00030671	-0.00017099	0.00020134	0.00017805	-0.00000025	0.00003928
7	97,261,052	*rs41656987*	0.00104868	0.00048033	0.00017963	-0.00001059	0.00011002	0.00011454
7	97,372,656	*rs41570922*	-0.00026557	-0.00024736	0.00001186	-0.00013418	-0.00004761	0.00001181
7	97,393,157	*rs41615915*	-0.00090198	0.00002637	-0.00048107	0.00000907	-0.00003997	-0.00007934
7	97,430,691	*ss86295638*	0.00074568	-0.00001324	0.00047692	-0.00012040	-0.00002678	0.00005340
7	97,501,859	*ss86310801*	-0.00039152	-0.00006694	-0.00012889	-0.00017279	0.00005665	-0.00004583
7	97,529,872	*ss61472319*	0.00045326	-0.00025686	0.00042590	-0.00019590	0.00007461	-0.00001851
7	97,691,853	*ss86290016*	0.00012060	0.00008623	0.00002409	0.00016817	0.00000658	-0.00002851
7	97,772,240	*ss86312419*	-0.00046509	-0.00038513	-0.00026961	-0.00010804	0.00004202	0.00000432
7	97,861,341	*rs41593284*	0.00097782	0.00011997	0.00031705	-0.00007204	0.00019796	0.00004403
7	97,898,940	*rs41593281*	0.00155220	0.00034795	0.00080756	0.00016613	0.00001148	0.00007858
7	97,961,659	*ss117969141*	0.00015075	0.00014493	0.00001131	0.00000912	0.00000444	0.00002638
7	98,013,150	*ss117968909*	0.00006102	-0.00010369	-0.00046716	0.00050154	0.00002137	0.00016343
7	98,173,299	*ss86290989*	0.00012363	0.00009822	-0.00022941	0.00049209	0.00001609	0.00001944
7	98,194,828	*rs41658549*	-0.00007628	-0.00045406	0.00038728	-0.00109154	0.00001558	0.00004740
7	98,254,815	*rs41658542*	0.00037965	-0.00015143	0.00060092	-0.00081707	-0.00005474	0.00003396
7	98,375,640	*ss86329349*	0.00085501	0.00051810	0.00043447	0.00001862	0.00002704	-0.00001097
7	98,495,888	*rs43529872*	0.00250806	0.00083827	0.00110064	0.00117126	0.00009663	-0.00003567
7	98,498,047	*ss86321563*	0.00251152	0.00094639	0.00113500	0.00114492	0.00007645	-0.00004943
7	98,538,952	*rs41660170*	0.00051614	0.00046201	-0.00000394	0.00034683	0.00001636	0.00003628
7	98,566,391	*ss117962527*	-0.00091729	-0.00063906	-0.00007139	-0.00081305	-0.00003279	0.00000133
7	98,579,574	*rs41255587*	0.00282846	0.00097459	0.00114941	0.00135049	0.00010269	-0.00002145
7	98,635,208	*ss86300200*	-0.00163961	-0.00033048	-0.00094817	0.00033141	-0.00008345	-0.00007121
7	98,646,770	*rs41596489*	0.00165452	0.00083405	0.00091620	0.00001794	0.00003965	0.00001667
7	98,680,293	*ss86315737*	-0.00122381	-0.00087793	-0.00080722	0.00022035	0.00004635	-0.00000223
7	98,726,055	*rs29018251*	0.00039725	-0.00079091	0.00029255	0.00047142	0.00000296	0.00002039
7	98,757,265	*ss86303738*	0.00031484	-0.00013005	0.00007134	0.00019325	-0.00000945	0.00008748
7	98,820,742	*ss86324113*	0.00133604	0.00080850	0.00064476	-0.00010404	-0.00002931	0.00011256
7	98,887,313	*rs41568595*	-0.00035467	0.00004527	-0.00006420	-0.00040082	0.00000383	-0.00001382
7	98,907,404	*ss86291843*	-0.00049765	-0.00001049	-0.00023992	-0.00019419	-0.00008403	0.00003096
7	98,974,456	*ss86339659*	0.00053311	0.00025554	0.00028576	0.00013611	0.00002468	0.00001069
7	99,024,444	*ss117968912*	-0.00020917	-0.00019566	0.00028752	-0.00066185	0.00004319	-0.00005451
7	99,085,299	*rs41590403*	-0.00048724	-0.00019597	0.00009020	-0.00037474	-0.00008357	-0.00001654
7	99,130,598	*ss86333606*	-0.00084381	0.00004792	-0.00082834	0.00005799	0.00001115	0.00006039
7	99,178,748	*rs41568774*	-0.00008141	-0.00004854	0.00014285	-0.00003014	-0.00004148	-0.00003983
7	99,215,474	*ss86324013*	0.00060578	0.00002168	0.00043622	-0.00002909	0.00000885	-0.00002556
7	99,344,820	*rs41622872*	-0.00089371	0.00019432	-0.00059364	0.00017413	-0.00010856	-0.00007464
7	99,399,852	*ss117968895*	0.00004348	-0.00022947	0.00011675	-0.00000801	-0.00000804	-0.00000512
7	99,492,904	*ss86296856*	-0.00059036	-0.00048595	-0.00029855	-0.00000510	-0.00000663	0.00000746
7	99,635,841	*ss86339853*	0.00010124	0.00004271	0.00022532	-0.00041791	0.00005579	-0.00007081
7	99,687,614	*rs41657025*	0.00027601	-0.00044383	0.00011698	0.00026276	-0.00000252	0.00008263
7	99,845,133	*rs41624339*	0.00087822	0.00010669	0.00041919	0.00028876	-0.00004153	0.00006660
7	99,919,908	*ss86339607*	0.00005831	-0.00007035	-0.00000100	0.00031240	0.00004996	-0.00003941
7	100,015,468	*ss86310226*	-0.00015773	0.00012360	-0.00002482	-0.00037122	0.00005151	-0.00004723
29	42,406,544	*ss86319674*	0.00004412	0.00050562	-0.00006947	-0.00016157	0.00003160	-0.00003943
29	42,455,680	*ss117974470*	-0.00023668	-0.00003069	0.00008615	0.00009795	-0.00007734	-0.00007606
29	42,620,218	*rs42189770*	0.00006534	0.00010962	-0.00011858	0.00039419	-0.00001053	-0.00001761
29	42,651,294	*rs43706142*	-0.00015187	-0.00070089	0.00012322	-0.00029180	0.00001081	0.00001108
29	42,696,595	*rs42189112*	0.00044366	0.00053810	-0.00019729	0.00082689	-0.00000348	0.00008903
29	42,749,808	*rs29020063*	-0.00015364	0.00030458	0.00006338	-0.00061076	0.00005270	-0.00012279
29	42,842,353	*ss117974486*	-0.00051136	-0.00047485	0.00025958	0.00014454	-0.00007630	-0.00023417
29	42,897,144	*ss86322358*	0.00016974	-0.00027606	0.00004743	0.00011962	-0.00001069	0.00007674

29	43,006,000	*ss86339964*		0.00009489	-0.00034623	0.00004546	0.00011962	-0.00001069	0.00006409
29	43,043,207	*ss86341572*		0.00026966	-0.00049034	0.00004519	0.00049483	-0.00005195	0.00009832
29	43,108,445	*ss86337140*		-0.00106080	-0.00067556	-0.00036196	-0.00021056	-0.00002031	-0.00007203
29	43,129,250	*ss86337549*		-0.00053788	-0.00077763	-0.00001082	-0.00002855	-0.00006132	-0.00003243
29	43,189,370	*ss86319044*		-0.00047528	-0.00077860	-0.00001082	-0.00001117	-0.00004383	-0.00003243
29	43,224,753	*rs29013208*		0.00048618	0.00073297	-0.00001707	-0.00011758	0.00004316	0.00006908
29	43,269,744	*ss86282762*		0.00032969	0.00063292	-0.00001988	-0.00014031	0.00003155	0.00002805
29	43,304,256	*rs29024708*		-0.00062896	-0.00068295	0.00012981	-0.00017576	-0.00001246	-0.00016043
29	43,328,607	*ss86295061*		0.00006312	0.00060219	-0.00022979	0.00033339	0.00002294	-0.00002393
29	43,429,511	*ss86318094*		-0.00160847	-0.00115096	-0.00079603	0.00019993	-0.00005774	-0.00007607
29	43,466,342	*ss86310741*		-0.00055100	-0.00078488	-0.00011944	-0.00031762	0.00007341	-0.00005915
29	43,498,073	*ss86338800*		0.00093454	0.00075831	0.00008009	0.00073932	-0.00005284	0.00009236
29	43,611,640	*ss86298040*		0.00146282	0.00030516	0.00040305	0.00095462	-0.00002067	0.00017820
29	43,652,252	*ss86327310*		-0.00118582	-0.00130334	-0.00027823	-0.00006298	-0.00004581	-0.00012680
29	43,686,401	*ss86325323*		-0.00012415	-0.00073056	-0.00022126	0.00033263	0.00000339	0.00004428
29	43,709,769	*ss86290081*		-0.00057947	-0.00100397	-0.00032111	0.00036105	0.00004399	-0.00004252
29	43,747,765	*rs42190085*		-0.00049735	-0.00020965	0.00001155	-0.00038731	-0.00002178	-0.00002225
29	43,749,527	*ss86299346*		-0.00019238	0.00016220	0.00001596	-0.00023397	-0.00000979	-0.00003480
29	43,777,249	*ss86299989*		-0.00006297	-0.00065114	-0.00002619	0.00022008	0.00000151	-0.00001811
29	43,826,144	*rs42191289*		0.00010758	0.00057745	-0.00022997	-0.00017228	-0.00006867	0.00017586
29	43,839,783	*ss86336460*		0.00061942	0.00081131	-0.00022565	0.00045409	-0.00003884	0.00020882
29	43,914,923	*ss86335514*		0.00178742	0.00045442	0.00036472	0.00105531	0.00006568	0.00019156
29	44,000,728	*rs42191319*		-0.00023431	0.00000024	-0.00020306	0.00014559	-0.00002916	0.00001428
29	44,029,526	*rs42192038*		-0.00092400	-0.00046153	-0.00009380	-0.00050894	-0.00003445	-0.00014690
29	44,042,363	*rs42192064*		-0.00185121	-0.00101148	-0.00035929	-0.00032758	0.00001350	-0.00033390
29	44,049,244	*rs42192077*		0.00051167	-0.00024213	0.00042010	0.00009658	-0.00000003	-0.00001236
29	44,050,471	*ss86284058*		-0.00072640	0.00013171	-0.00053768	-0.00038629	-0.00001074	0.00005388
29	44,051,567	*rs42192079*		-0.00044039	0.00017368	-0.00037741	-0.00009999	-0.00000151	0.00001440
29	44,053,733	*rs42192083*		0.00041510	-0.00023030	0.00038673	0.00007379	0.00000561	-0.00001662
29	44,054,901	*rs42192084*		0.00023354	-0.00015260	0.00019889	0.00029494	0.00001567	-0.00004086
29	44,058,688	*rs42192090*		0.00056930	0.00065475	-0.00014365	0.00097619	-0.00005793	0.00006581
29	44,060,410	*rs42192096*		-0.00052571	-0.00066766	0.00021685	-0.00076421	0.00003819	-0.00009649
29	44,062,694	*rs42192100*		-0.00050977	-0.00067190	0.00021482	-0.00070708	0.00003338	-0.00009162
29	44,063,938	*rs17872078*		-0.00295459	-0.00157336	-0.00080065	-0.00130368	-0.00001613	-0.00023251
29	44,067,234	*rs17872093*		0.00046438	0.00066766	-0.00027634	0.00076421	-0.00003338	0.00009915
29	44,067,796	*rs17871984*		0.00259095	0.00120226	0.00104514	0.00063915	0.00003574	0.00015159
29	44,068,143	*rs17870631*		0.00317238	0.00186992	0.00083717	0.00140771	0.00000236	0.00025628
29	44,068,346	*rs17870628*		0.00242209	0.00143725	0.00086741	0.00078922	-0.00002876	0.00016684
29	44,068,445	*rs17870626*		0.00308636	0.00178329	0.00081694	0.00138681	-0.00001299	0.00025696
29	44,068,519	*rs17872010*		0.00304194	0.00181486	0.00079066	0.00140771	0.00000236	0.00024530
29	44,068,580	*rs17872004*		0.00313874	0.00186992	0.00082829	0.00139445	0.00000629	0.00024985
29	44,068,812	*rs17872003*		-0.00312101	-0.00188257	-0.00082610	-0.00143916	0.00000748	-0.00024616
29	44,069,063	*rs17812000*		-0.00316072	-0.00228185	-0.00073880	-0.00140771	-0.00000236	-0.00024894
29	44,069,177	*rs17872006*		-0.00290630	-0.00194198	-0.00076244	-0.00120636	0.00002461	-0.00024429
29	44,070,713	*rs42192103*		-0.00332608	-0.00173409	-0.00094128	-0.00152269	0.00002317	-0.00028201
29	44,070,881	*rs42192105*		-0.00114491	-0.00046199	-0.00062239	-0.00008699	0.00000425	-0.00006435
29	44,071,034	*rs42192107*		-0.00110210	-0.00046869	-0.00062781	-0.00017354	0.00000425	-0.00003314
29	44,071,135	*rs42192108*		-0.00044909	-0.00004798	-0.00010125	-0.00018521	-0.00006208	-0.00000408
29	44,071,593	*rs42192109*		-0.00094890	-0.00100318	0.00008230	-0.00107584	0.00005396	-0.00010545
29	44,085,642	*rs17871051*		0.00181650	0.00134971	0.00024034	0.00077510	0.00009067	0.00018604
29	44,085,769	*rs17871058*		0.00236870	0.00130304	0.00021437	0.00146508	0.00018454	0.00021263
29	44,087,205	*rs17872032*		0.00096858	0.00059348	0.00002368	0.00061874	0.00004608	0.00010203
29	44,087,356	*rs17872033*		-0.00172481	-0.00132279	-0.00023887	-0.00074441	-0.00010755	-0.00016116
29	44,087,629	*rs17872050*		0.00241788	0.00143400	0.00021062	0.00148598	0.00019989	0.00020641
29	44,087,858	*rs17872151*		0.00053210	-0.00001758	0.00011545	0.00030835	0.00002839	0.00003877

29	44,088,897	*rs17870847*	-0.00236640	-0.00134853	-0.00018849	-0.00152169	-0.00019782	-0.00019442
29	44,110,295	*rs42192119*	-0.00020159	0.00009268	-0.00003017	-0.00033493	-0.00003855	0.00001843
29	44,119,671	*rs42195143*	0.00016832	-0.00029353	0.00040275	-0.00006054	0.00001746	-0.00002797
29	44,122,272	*rs42194216*	-0.00031009	0.00011168	-0.00025424	-0.00012528	0.00001347	-0.00000075
29	44,125,747	*rs42194178*	-0.00032379	0.00014293	-0.00028060	-0.00012467	0.00001347	-0.00000075
29	44,130,887	*rs42194132*	0.00025708	-0.00014293	0.00026202	0.00012655	-0.00001347	-0.00001560
29	44,154,126	*rs42193349*	-0.00039133	0.00036022	-0.00029871	-0.00007837	0.00001820	-0.00003331
29	44,172,614	*ss117965984*	-0.00069936	0.00000948	-0.00031668	-0.00035165	0.00002555	-0.00008372
29	44,196,154	*ss86318958*	0.00014359	0.00029049	0.00024258	-0.00017471	0.00000858	-0.00001230
29	44,208,978	*rs29003633*	0.00027473	0.00067584	0.00000504	0.00005976	-0.00000215	-0.00002063
29	44,223,148	*ss86323783*	0.00095480	0.00108636	0.00002128	0.00075592	0.00006222	0.00002016
29	44,243,444	*ss86313099*	-0.00010319	0.00085706	-0.00056913	0.00050513	0.00001353	-0.00003883
29	44,325,408	*ss86292140*	-0.00161978	-0.00161585	-0.00017661	-0.00061998	-0.00004278	-0.00014539
29	44,372,611	*ss86329852*	-0.00035147	0.00002025	-0.00012224	-0.00059268	-0.00006096	0.00007161
29	44,395,075	*ss86333994*	-0.00120791	-0.00077009	-0.00038065	0.00006199	-0.00002805	-0.00017409
29	44,416,282	*rs43709648*	-0.00203603	-0.00103453	-0.00093446	-0.00067339	-0.00001133	-0.00005219
29	44,546,564	*ss86288185*	0.00110217	0.00069894	0.00045516	0.00051185	-0.00000784	0.00005656
29	44,585,782	*ss86341172*	-0.00075142	-0.00059974	-0.00022848	-0.00066809	0.00004126	-0.00004148
29	44,628,137	*rs41600300*	-0.00005648	0.00034145	0.00005371	0.00013032	-0.00004817	-0.00003908
29	44,649,908	*ss86337530*	0.00005313	-0.00008978	0.00038621	-0.00022923	0.00001713	-0.00009300
29	44,740,917	*ss86334185*	0.00079430	0.00082804	0.00038222	-0.00025986	0.00002142	0.00002880
29	44,807,928	*ss117965824*	-0.00026913	0.00079928	-0.00045557	0.00002440	0.00000569	0.00002481
29	44,853,970	*rs42192429*	0.00005315	-0.00107690	0.00013023	-0.00052061	0.00003071	0.00010706
29	44,900,940	*rs43706228*	0.00089149	0.00166157	-0.00007800	0.00120207	-0.00000796	-0.00002885
29	44,969,518	*ss86337154*	-0.00025376	-0.00008685	0.00002682	-0.00024640	-0.00002614	-0.00002386
29	44,979,377	*ss86338214*	0.00021114	0.00036588	-0.00018187	0.00021199	0.00001482	0.00006627
29	44,999,264	*ss86310727*	0.00133191	0.00075573	0.00004545	0.00060918	0.00010639	0.00015623
29	45,023,665	*ss86338763*	-0.00019088	-0.00008685	0.00005425	-0.00023066	-0.00002614	-0.00001956
29	45,102,557	*ss86332221*	-0.00129469	-0.00064203	-0.00004862	-0.00111294	0.00001335	-0.00016787
29	45,129,099	*ss86335405*	0.00063776	0.00065799	0.00007693	0.00047129	0.00001030	0.00002804
29	45,187,114	*ss86295760*	-0.00047535	-0.00087672	-0.00015742	-0.00006285	-0.00002459	0.00001400
29	45,287,502	*ss86312485*	0.00053477	0.00045858	0.00002288	0.00071079	0.00001575	-0.00000847
29	45,326,585	*rs42198683*	0.00021305	0.00027334	-0.00028774	0.00099702	0.00001472	-0.00005160
29	45,367,095	*ss86322638*	0.00039329	0.00031861	0.00033922	-0.00017070	0.00003571	-0.00007839
29	45,458,280	*rs43706176*	-0.00020553	-0.00045743	0.00003098	-0.00005162	-0.00002502	0.00000069
29	45,482,143	*rs29025626*	-0.00084208	-0.00104550	-0.00002985	-0.00024322	-0.00010494	-0.00004481
29	45,530,264	*ss86341375*	0.00019820	0.00005755	0.00002545	-0.00001078	0.00003298	0.00003977

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and green for the within-

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relationship matrix.

[6]-$\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are shaded in red. Oth

[7]-$\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum values are shaded i

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP block centered on

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

						ASE[5]		
BTA	POS[1]	SNP ID[2]	β-All Breeds	β-Angus	β-Hereford	β-Charolais	β-Limousin	β-Simmental
7	97,151,592	*rs41656985*	0.01377207	-0.01999276	0.03740770	0.01615795	-0.00029396	0.03399697
7	97,261,052	*rs41656987*	0.06407879	0.08585839	0.05622007	-0.00113931	0.15788787	0.11469922
7	97,372,656	*rs41570922*	-0.04721657	-0.10888501	0.02478650	-0.03871002	-0.15544713	0.02536908
7	97,393,157	*rs41615915*	-0.04605863	0.00265377	-0.10743993	0.00108729	-0.05573660	-0.07783973
7	97,430,691	*ss86295638*	0.05460805	-0.00518239	0.10506659	-0.02294942	-0.04461769	0.07698709
7	97,501,859	*ss86310801*	-0.03764247	-0.02495779	-0.04955234	-0.03468353	0.08999742	-0.09143018
7	97,529,872	*ss61472319*	0.02111581	-0.02877606	0.08140793	-0.01884309	0.10324757	-0.01642583
7	97,691,853	*ss86290016*	0.04112449	0.13325936	0.05822260	0.12703600	0.04074417	-0.09219867
7	97,772,240	*ss86312419*	-0.05640512	-0.07610179	-0.21729369	-0.02281948	0.30240522	0.00927325
7	97,861,341	*rs41593284*	0.05750871	0.01407221	0.11133231	-0.00899134	0.24638150	0.04204862
7	97,898,940	*rs41593281*	0.09632991	0.07850543	0.14152236	0.04174867	0.01595788	0.08909754
7	97,961,659	*ss117969141*	0.04610124	0.12701127	0.01169940	0.00594871	0.04862822	0.17698328
7	98,013,150	*ss117968909*	0.00300209	-0.01193793	-0.09714359	0.05201490	0.02690835	0.15605575
7	98,173,299	*ss86290989*	0.00767338	0.01261753	-0.06474281	0.07826779	0.01956097	0.02321594
7	98,194,828	*rs41658549*	-0.00401437	-0.04982220	0.09135510	-0.13132990	0.02229160	0.04134878
7	98,254,815	*rs41658542*	0.02188950	-0.01574779	0.20327112	-0.10260593	-0.07012338	0.03239528
7	98,375,640	*ss86329349*	0.09183851	0.12926199	0.20569660	0.00380099	0.11857929	-0.02275644
7	98,495,888	*rs43529872*	0.14912943	0.12638542	0.20438144	0.18318184	0.24750333	-0.03846871
7	98,498,047	*ss86321563*	0.14221431	0.15154723	0.20916753	0.15264208	0.18729389	-0.04713413
7	98,538,952	*rs41660170*	0.07895436	0.13526771	-0.00409153	0.08051120	0.07729644	0.11766511
7	98,566,391	*ss117962527*	-0.09262624	-0.16100475	-0.06040231	-0.16610346	-0.05483045	0.00153287
7	98,579,574	*rs41255587*	0.15449911	0.14576743	0.21255338	0.19065204	0.14454926	-0.02075111
7	98,635,208	*ss86300200*	-0.07152941	-0.03340736	-0.16969513	0.03199936	-0.10216313	-0.05727451
7	98,646,770	*rs41596489*	0.08027895	0.08287525	0.18982409	0.00170165	0.06672588	0.01508636
7	98,680,293	*ss86315737*	-0.05859165	-0.10106432	-0.15573983	0.02425142	0.06258840	-0.00192055
7	98,726,055	*rs29018251*	0.02359443	-0.12618996	0.07884128	0.05065498	0.00635118	0.01937443
7	98,757,265	*ss86303738*	0.02532671	-0.01615925	0.05567595	0.03238808	-0.01262411	0.11054776
7	98,820,742	*ss86324113*	0.07294052	0.08716323	0.17291781	-0.01161769	-0.05684945	0.10538010
7	98,887,313	*rs41568595*	-0.03694200	0.01652002	-0.02094997	-0.18933093	0.00660686	-0.02603140
7	98,907,404	*ss86291843*	-0.02347963	-0.00112256	-0.03939083	-0.02093560	-0.12977007	0.03256895
7	98,974,456	*ss86339659*	0.02520614	0.02355067	0.04765437	0.01524006	0.04806978	0.01211776
7	99,024,444	*ss117968912*	-0.00962625	-0.02314016	0.04887861	-0.06772105	0.06137752	-0.05045382
7	99,085,299	*rs41590403*	-0.03960914	-0.05700088	0.02546463	-0.07769533	-0.22934220	-0.01881188
7	99,130,598	*ss86333606*	-0.06239241	0.00956325	-0.14975990	0.02080513	0.03399904	0.11373474
7	99,178,748	*rs41568774*	-0.00494952	-0.00595571	0.04305756	-0.00422053	-0.06928228	-0.03732380
7	99,215,474	*ss86324013*	0.03866208	0.00323942	0.13672049	-0.00375089	0.01211855	-0.03134186
7	99,344,820	*rs41622872*	-0.04295510	0.02002393	-0.12011580	0.01951865	-0.13440981	-0.07138409
7	99,399,852	*ss117968895*	0.00566668	-0.05979255	0.05792219	-0.00246880	-0.06191476	-0.01295397
7	99,492,904	*ss86296856*	-0.06625218	-0.10116761	-0.17772993	-0.00151215	-0.01224771	0.01697012
7	99,635,841	*ss86339853*	0.00560736	0.00581627	0.05035461	-0.05124237	0.08750034	-0.07198733
7	99,687,614	*rs41657025*	0.01600630	-0.05598055	0.03944556	0.02693623	-0.00419388	0.07459634
7	99,845,133	*rs41624339*	0.05420017	0.01451857	0.08271281	0.04128013	-0.15385321	0.10367658
7	99,919,908	*ss86339607*	0.00320745	-0.00812169	-0.00021135	0.05011518	0.06678217	-0.03988769
7	100,015,468	*ss86310226*	-0.00884300	0.01313929	-0.00799969	-0.04322683	0.07312651	-0.04484400
29	42,406,544	*ss86319674*	0.00499755	0.13127994	-0.02539683	-0.05011073	0.37427564	-0.07250370
29	42,455,680	*ss117974470*	-0.01114205	-0.00287066	0.01625321	0.01350677	-0.08903101	-0.06311767
29	42,620,218	*rs42189770*	0.00437862	0.01893309	-0.02713130	0.07412626	-0.02035679	-0.02046697
29	42,651,294	*rs43706142*	-0.00912868	-0.07832798	0.04644727	-0.03432996	0.01516783	0.01150035
29	42,696,595	*rs42189112*	0.02244031	0.06801028	-0.03648918	0.10811249	-0.00408642	0.08595896
29	42,749,808	*rs29020063*	-0.00802797	0.03088923	0.01431881	-0.08214113	0.06422537	-0.11007124
29	42,842,353	*ss117974486*	-0.02723432	-0.05483318	0.06254769	0.01804422	-0.09758154	-0.20088805
29	42,897,144	*ss86322358*	0.01390338	-0.04068813	0.02886829	0.01772594	-0.01746038	0.10763037

29	43,006,000	*ss86339964*	0.00786039	-0.05214215	0.02769884	0.01772594	-0.01746038	0.09288296
29	43,043,207	*ss86341572*	0.01905446	-0.06102574	0.02423195	0.06732475	-0.08042507	0.10649011
29	43,108,445	*ss86337140*	-0.09515691	-0.18767192	-0.13426794	-0.05009274	-0.03198651	-0.10713556
29	43,129,250	*ss86337549*	-0.11213504	-0.36449310	-0.05938852	-0.01576700	-0.11245798	-0.07599159
29	43,189,370	*ss86319044*	-0.09177632	-0.35818174	-0.05938852	-0.00449407	-0.08165142	-0.07599159
29	43,224,753	*rs29013208*	0.07685161	0.23681481	-0.06367290	-0.03767127	0.07834478	0.13411425
29	43,269,744	*ss86282762*	0.06673067	0.22340633	-0.08516222	-0.04797645	0.06672672	0.13893634
29	43,304,256	*rs29024708*	-0.05533914	-0.18017752	0.05280083	-0.03602372	-0.02059741	-0.21167262
29	43,328,607	*ss86295061*	0.00409931	0.06677072	-0.08406764	0.05513809	0.03738891	-0.02303009
29	43,429,511	*ss86318094*	-0.08927452	-0.11940061	-0.19002689	0.02397019	-0.17416374	-0.07217357
29	43,466,342	*ss86310741*	-0.05527207	-0.18298300	-0.03897509	-0.08345126	0.21664736	-0.15334543
29	43,498,073	*ss86338800*	0.05956164	0.11996911	0.01582097	0.12870934	-0.13744882	0.12546311
29	43,611,640	*ss86298040*	0.07322512	0.03240417	0.07923634	0.11566400	-0.02602530	0.17796485
29	43,652,252	*ss86327310*	-0.05350543	-0.13120156	-0.04690503	-0.00705293	-0.05862478	-0.10243448
29	43,686,401	*ss86325323*	-0.01025002	-0.12481137	-0.05790675	0.07998412	0.02080392	0.07436958
29	43,709,769	*ss86290081*	-0.03614715	-0.09808855	-0.14603245	0.04284288	0.06642355	-0.04706384
29	43,747,765	*rs42190085*	-0.03252887	-0.03454110	0.00266994	-0.06688717	-0.03643018	-0.02716611
29	43,749,527	*ss86299346*	-0.01815565	0.04194873	0.00506304	-0.04813533	-0.07093084	-0.05943258
29	43,777,249	*ss86299989*	-0.00379751	-0.08865721	-0.00587409	0.03403038	0.00214447	-0.02166572
29	43,826,144	*rs42191289*	0.00538920	0.08261932	-0.04308125	-0.01792714	-0.10331144	0.16352930
29	43,839,783	*ss86336460*	0.02873918	0.09722623	-0.03889303	0.04674230	-0.05443953	0.17591056
29	43,914,923	*ss86335514*	0.14099316	0.12325906	0.11582581	0.17858418	0.10103476	0.27239461
29	44,000,728	*rs42191319*	-0.02134130	0.00009678	-0.04485603	0.05849863	-0.10881374	0.02442284
29	44,029,526	*rs42192038*	-0.04465678	-0.04790513	-0.01687600	-0.05861484	-0.06926916	-0.12931805
29	44,042,363	*rs42192064*	-0.09088154	-0.11220353	-0.06259312	-0.03927838	0.01761857	-0.31307293
29	44,049,244	*rs42192077*	0.02578055	-0.02692225	0.08254911	0.01055042	-0.00004142	-0.01123121
29	44,050,471	*ss86284058*	-0.06361724	0.02388787	-0.19851647	-0.07943526	-0.02527633	0.08868873
29	44,051,567	*rs42192079*	-0.02210319	0.01920409	-0.07340928	-0.01089515	-0.00185196	0.01290773
29	44,053,733	*rs42192083*	0.02086679	-0.02545535	0.07588543	0.00806255	0.00679728	-0.01483180
29	44,054,901	*rs42192084*	0.01512321	-0.02258374	0.04596259	0.04186951	0.02413509	-0.05674960
29	44,058,688	*rs42192090*	0.02968789	0.06906875	-0.02816224	0.11941891	-0.07838293	0.05512612
29	44,060,410	*rs42192096*	-0.02832327	-0.07343302	0.04272696	-0.09131420	0.06035150	-0.08307020
29	44,062,694	*rs42192100*	-0.02736293	-0.07396977	0.04226760	-0.08474445	0.05322737	-0.07665678
29	44,063,938	*rs17872078*	-0.18564305	-0.18455479	-0.20510618	-0.16345367	-0.03249970	-0.23021449
29	44,067,234	*rs17872093*	0.02496105	0.07343302	-0.05406733	0.09131420	-0.05322737	0.08515734
29	44,067,796	*rs17871984*	0.17226965	0.20960280	0.25854084	0.10460733	0.08033891	0.14060072
29	44,068,143	*rs17870631*	0.23869986	0.22119704	0.24379122	0.22023146	0.00547252	0.34767985
29	44,068,346	*rs17870628*	0.16042843	0.15402954	0.24841222	0.10918790	-0.05396674	0.19102806
29	44,068,445	*rs17870626*	0.22829997	0.21152447	0.23663609	0.21618169	-0.02950121	0.32679359
29	44,068,519	*rs17872010*	0.22980629	0.21678554	0.23000251	0.22023146	0.00547252	0.33560285
29	44,068,580	*rs17872004*	0.23576592	0.22119704	0.24158328	0.21914000	0.01402673	0.33693156
29	44,068,812	*rs17872003*	-0.23425299	-0.22039076	-0.24087221	-0.22570015	0.01719659	-0.33744060
29	44,069,063	*rs17812000*	-0.23938706	-0.27604109	-0.21680105	-0.22023146	-0.00547252	-0.33888089
29	44,069,177	*rs17872006*	-0.20865952	-0.22809167	-0.21525294	-0.17836251	0.05335006	-0.31640257
29	44,070,713	*rs42192103*	-0.23126101	-0.20077133	-0.25377584	-0.23262707	0.04616506	-0.33919363
29	44,070,881	*rs42192105*	-0.13150092	-0.09916322	-0.20618399	-0.03162694	0.02776421	-0.16146931
29	44,071,034	*rs42192107*	-0.14426575	-0.11047033	-0.21343493	-0.07328780	0.02776421	-0.16118552
29	44,071,135	*rs42192108*	-0.05688668	-0.02886829	-0.03653651	-0.04193928	-0.29972195	-0.02004771
29	44,071,593	*rs42192109*	-0.05027538	-0.10884482	0.01585778	-0.12844689	0.08759822	-0.09627713
29	44,085,642	*rs17871051*	0.14188557	0.30364766	0.10809754	0.11126940	0.13503153	0.20082779
29	44,085,769	*rs17871058*	0.14392345	0.15281348	0.06846588	0.18131448	0.28735643	0.19762528
29	44,087,205	*rs17872032*	0.18873706	0.25640780	0.03850535	0.20027467	0.15725079	0.30972904
29	44,087,356	*rs17872033*	-0.12775860	-0.27170879	-0.10219163	-0.10479101	-0.15498932	-0.15942987
29	44,087,629	*rs17872050*	0.14442059	0.16563130	0.06653446	0.18413259	0.30762227	0.17956041
29	44,087,858	*rs17872151*	0.14001255	-0.02272857	0.30154212	0.12323939	0.07713691	0.18930825

29	44,088,897	*rs17870847*	-0.14124160	-0.15463556	-0.05878994	-0.18885633	-0.30340823	-0.17524866
29	44,110,295	*rs42192119*	-0.01942996	0.01451903	-0.02155698	-0.06463021	-0.08669320	0.03046439
29	44,119,671	*rs42195143*	0.00783300	-0.02935938	0.07389328	-0.00669293	0.02115000	-0.02711373
29	44,122,272	*rs42194216*	-0.03172111	0.02819610	-0.08098997	-0.04973577	0.02964052	-0.00160258
29	44,125,747	*rs42194178*	-0.03356792	0.03659072	-0.09186858	-0.04942879	0.02964052	-0.00160258
29	44,130,887	*rs42194132*	0.02644605	-0.03659072	0.08421906	0.05072096	-0.02964052	-0.03311083
29	44,154,126	*rs42193349*	-0.05305730	0.22356813	-0.10323256	-0.05776275	0.04588778	-0.09831775
29	44,172,614	*ss117965984*	-0.03964292	0.00112919	-0.06918327	-0.04362937	0.04977295	-0.10354199
29	44,196,154	*ss86318958*	0.01564406	0.11621015	0.08928295	-0.04546044	0.03894493	-0.02006039
29	44,208,978	*rs29003633*	0.07439988	0.43869793	0.00575558	0.03243145	-0.04998931	-0.08817917
29	44,223,148	*ss86323783*	0.07582241	0.21702321	0.00803405	0.12606020	0.13368766	0.02592427
29	44,243,444	*ss86313099*	-0.00549653	0.11812362	-0.10476431	0.08059616	0.02143301	-0.03460116
29	44,325,408	*ss86292140*	-0.16398496	-0.20530041	-0.19003334	-0.12468567	-0.10603965	-0.24574655
29	44,372,611	*ss86329852*	-0.03713291	0.00488436	-0.08660821	-0.09708762	-0.17343672	0.13482641
29	44,395,075	*ss86333994*	-0.06754849	-0.10992804	-0.09616456	0.00711078	-0.03712152	-0.16178806
29	44,416,282	*rs43709648*	-0.13069556	-0.28351741	-0.18944356	-0.09438042	-0.01593376	-0.08385696
29	44,546,564	*ss86288185*	0.05494993	0.09262489	0.08928476	0.05312496	-0.01034263	0.05095507
29	44,585,782	*ss86341172*	-0.03866292	-0.06206035	-0.05039949	-0.08198585	0.06203462	-0.03992657
29	44,628,137	*rs41600300*	-0.01483796	0.20889018	0.15455551	0.06038629	-0.18452356	-0.14991919
29	44,649,908	*ss86337530*	0.00294146	-0.01196893	0.08771622	-0.02822089	0.02041584	-0.09897733
29	44,740,917	*ss86334185*	0.05012176	0.10695692	0.08835503	-0.03612618	0.10055830	0.03904043
29	44,807,928	*ss117965824*	-0.01428477	0.10722949	-0.08601306	0.00337124	0.00765424	0.02422262
29	44,853,970	*rs42192429*	0.00310823	-0.14208317	0.02747885	-0.07932534	0.06115144	0.11080152
29	44,900,940	*rs43706228*	0.04401726	0.16432737	-0.01507454	0.14127813	-0.01453902	-0.02478305
29	44,969,518	*ss86337154*	-0.08569177	-0.09080754	0.27706137	-0.16974889	-0.08763089	-0.07547633
29	44,979,377	*ss86338214*	0.00973100	0.03288093	-0.03428688	0.02287154	0.02023673	0.05906225
29	44,999,264	*ss86310727*	0.07636034	0.08409333	0.01064296	0.09008127	0.16345165	0.16162329
29	45,023,665	*ss86338763*	-0.06266468	-0.09080754	0.56904494	-0.14493435	-0.08763089	-0.06060103
29	45,102,557	*ss86332221*	-0.09128831	-0.10489015	-0.01759630	-0.20456570	0.01847027	-0.16251600
29	45,129,099	*ss86335405*	0.11751600	0.15237997	0.16724531	0.20802589	0.03794230	0.08782773
29	45,187,114	*ss86295760*	-0.02403866	-0.10408408	-0.03232491	-0.00787294	-0.03145318	0.01223186
29	45,287,502	*ss86312485*	0.09994421	0.09989672	0.05326782	0.21938837	0.26063282	-0.02542529
29	45,326,585	*rs42198683*	0.01064705	0.03273957	-0.05642473	0.10167291	0.02256656	-0.05231106
29	45,367,095	*ss86322638*	0.02307329	0.03872453	0.09838548	-0.01799483	0.09863873	-0.08139580
29	45,458,280	*rs43706176*	-0.02873231	-0.11397784	0.07484033	-0.01161712	-0.08531336	0.00126990
29	45,482,143	*rs29025626*	-0.05831395	-0.18623897	-0.00657759	-0.04365267	-0.32231770	-0.06272849
29	45,530,264	*ss86341375*	0.02131837	0.05111941	0.00589401	-0.00306374	0.15679441	0.20788969

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and green for the within

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relationship matrix.

[6]$-\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are shaded in red. Ot

[7]$-\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum values are shaded

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP block centered o

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

						-log$_{10}$(P)ASE[6]		
BTA	POS[1]	SNP ID[2]	β-All Breeds	β-Angus	β-Hereford	β-Charolais	β-Limousin	β-Simmental
7	97,151,592	*rs41656985*	0.25920819	0.19065791	0.38791104	0.17268288	0.00129203	0.24547389
7	97,261,052	*rs41656987*	1.76394501	0.96309267	0.46932913	0.00960706	1.15663403	1.13658381
7	97,372,656	*rs41570922*	0.51757650	0.70940830	0.06022060	0.24466141	0.62472795	0.10403711
7	97,393,157	*rs41615915*	1.21374534	0.02346959	1.51546840	0.00867879	0.28640193	0.65871607
7	97,430,691	*ss86295638*	1.19548289	0.02323031	1.47921826	0.16870415	0.19703810	0.49965269
7	97,501,859	*ss86310801*	0.57707351	0.12657802	0.34928548	0.26680432	0.48566729	0.50598038
7	97,529,872	*ss61472319*	0.43312604	0.30306271	1.11617585	0.19968551	0.64220544	0.10489070
7	97,691,853	*ss86290016*	0.28588801	0.40039921	0.14156066	0.60508426	0.08498000	0.37342394
7	97,772,240	*ss86312419*	0.86395033	0.75292586	1.67261725	0.15800490	0.91674896	0.03562833
7	97,861,341	*rs41593284*	1.53245331	0.12732425	1.13126148	0.07533843	2.64951708	0.29967328
7	97,898,940	*rs41593281*	3.42270182	0.71645917	2.89390082	0.29177371	0.06921540	0.71900816
7	97,961,659	*ss117969141*	0.35277075	0.54610435	0.03956972	0.02062259	0.07559241	0.54397980
7	98,013,150	*ss117968909*	0.04524314	0.10712272	1.36976476	0.69474730	0.12949977	1.90813017
7	98,173,299	*ss86290989*	0.10943140	0.10718998	0.60809591	0.91744683	0.09275246	0.13070592
7	98,194,828	*rs41658549*	0.05932558	0.62843426	1.13325108	2.56758808	0.09789700	0.31044044
7	98,254,815	*rs41658542*	0.39532965	0.15482480	3.06228709	1.65770810	0.40341524	0.21863565
7	98,375,640	*ss86329349*	1.99903332	1.38818084	2.35512143	0.02362894	0.35954871	0.09411136
7	98,495,888	*rs43529872*	7.74766418	1.99768902	5.22892170	3.62427416	1.47999444	0.24953504
7	98,498,047	*ss86321563*	7.42639931	2.56544376	5.48906355	3.03632723	1.00081075	0.34592414
7	98,538,952	*rs41660170*	1.19616937	1.31606193	0.01343470	0.72869343	0.20372510	0.51234229
7	98,566,391	*ss117962527*	2.13133465	1.95083162	0.27369699	2.44272959	0.25132133	0.00778098
7	98,579,574	*rs41255587*	8.94616131	2.54505254	5.63316775	4.25399597	1.02795263	0.12970451
7	98,635,208	*ss86300200*	2.78390969	0.39024136	3.88488884	0.38083683	0.68919867	0.49697830
7	98,646,770	*rs41596489*	3.09302733	1.42263877	4.15919781	0.01538183	0.31858437	0.09451937
7	98,680,293	*ss86315737*	1.85792616	1.73175280	3.13848683	0.24889004	0.33750113	0.01134466
7	98,726,055	*rs29018251*	0.42728013	1.90332787	0.82779401	0.65329731	0.02111718	0.12131636
7	98,757,265	*ss86303738*	0.38498763	0.14407068	0.26033788	0.27396792	0.05509740	0.90591284
7	98,820,742	*ss86324113*	2.38541310	1.44419614	2.83381698	0.10584866	0.24004092	1.05287378
7	98,887,313	*rs41568595*	0.53301860	0.08132593	0.13823755	1.53243070	0.02459171	0.11513550
7	98,907,404	*ss86291843*	0.49381227	0.00947962	0.44931494	0.21138458	0.82054150	0.20763072
7	98,974,456	*ss86339659*	0.54215062	0.26713043	0.57315687	0.14318927	0.19621006	0.06602532
7	99,024,444	*ss117968912*	0.16733868	0.22504722	0.58555919	1.02559764	0.31898397	0.38434202
7	99,085,299	*rs41590403*	0.69481474	0.39318251	0.18795130	0.75050635	1.24660458	0.10624050
7	99,130,598	*ss86333606*	1.45570588	0.06251611	3.10294183	0.10574727	0.10273524	0.70938049
7	99,178,748	*rs41568774*	0.06868082	0.04898987	0.34108982	0.03196463	0.33551761	0.26193372
7	99,215,474	*ss86324013*	0.79647808	0.02351372	1.69652140	0.02952516	0.05206018	0.18142548
7	99,344,820	*rs41622872*	1.14352553	0.20570883	1.95773851	0.19025349	1.01497461	0.59501667
7	99,399,852	*ss117968895*	0.05287460	0.44925767	0.36214999	0.01233920	0.11948527	0.04633037
7	99,492,904	*ss86296856*	1.15969824	1.09708746	1.54697553	0.00766042	0.04497447	0.06521665
7	99,635,841	*ss86339853*	0.08261138	0.04523761	0.50695580	0.60607729	0.47188976	0.57737955
7	99,687,614	*rs41657025*	0.26637232	0.67054698	0.28528814	0.29544248	0.01572183	0.65781175
7	99,845,133	*rs41624339*	1.34660053	0.12133397	1.11618627	0.41055563	0.56501728	0.71205727
7	99,919,908	*ss86339607*	0.04573644	0.07034137	0.00151539	0.49076674	0.36871254	0.27101227
7	100,015,468	*ss86310226*	0.13573436	0.12458893	0.04893090	0.49885840	0.39851707	0.32578504
29	42,406,544	*ss86319674*	0.04986806	1.37866264	0.16134861	0.32115619	0.87009257	0.39403172
29	42,455,680	*ss117974470*	0.19574411	0.02641378	0.14141656	0.11127875	0.59456400	0.55434182
29	42,620,218	*rs42189770*	0.05722611	0.14305650	0.22931731	0.75240467	0.07529309	0.11527340
29	42,651,294	*rs43706142*	0.13527357	1.19216972	0.32601885	0.36725161	0.06524151	0.06544274
29	42,696,595	*rs42189112*	0.44441091	0.88270802	0.37685810	1.74463604	0.01829748	0.76562942
29	42,749,808	*rs29020063*	0.12666589	0.35244490	0.11091297	1.11550797	0.37213472	1.16115545
29	42,842,353	*ss117974486*	0.55536657	0.69280424	0.64651365	0.16318906	0.62728700	3.18305827
29	42,897,144	*ss86322358*	0.18345331	0.39458459	0.13964490	0.14498396	0.06992430	0.80845199

29	43,006,000	*ss86339964*	0.09586061	0.53898948	0.13318280	0.14498396	0.06992430	0.64216062
29	43,043,207	*ss86341572*	0.29218063	0.76407239	0.12313821	0.82608844	0.42613324	0.96006708
29	43,108,445	*ss86337140*	2.45598566	2.31486819	1.44440671	0.37952271	0.13871960	0.77016154
29	43,129,250	*ss86337549*	1.61915754	4.63029649	0.09175169	0.06199632	0.59514087	0.35844100
29	43,189,370	*ss86319044*	1.25955168	4.56366938	0.09175169	0.01982073	0.38561856	0.35844100
29	43,224,753	*rs29013208*	1.12052175	3.01526390	0.12262529	0.22241437	0.37189194	0.87811532
29	43,269,744	*ss86282762*	0.76185346	2.53505836	0.15756175	0.28646199	0.27662167	0.48219951
29	43,304,256	*rs29024708*	1.06275615	2.25837870	0.36526377	0.27590072	0.08300408	2.41431365
29	43,328,607	*ss86295061*	0.05426188	0.94535620	0.72983337	0.54636948	0.16252304	0.14634925
29	43,429,511	*ss86318094*	3.30593304	2.47535623	3.68132176	0.23311529	0.77433371	0.60737632
29	43,466,342	*ss86310741*	0.96296598	2.56839941	0.28684653	0.70252500	1.08226275	0.86478838
29	43,498,073	*ss86338800*	1.52028312	1.76670225	0.13365834	1.83411013	0.61664702	1.03469542
29	43,611,640	*ss86298040*	2.58028835	0.36374051	1.04977109	2.06890532	0.12475821	2.28082929
29	43,652,252	*ss86327310*	1.68525775	2.97699466	0.55688163	0.06156001	0.32155822	1.12682579
29	43,686,401	*ss86325323*	0.12890225	1.76992464	0.55000156	0.70435872	0.04177780	0.43177499
29	43,709,769	*ss86290081*	0.73588744	1.88286213	1.40490730	0.48685638	0.33902519	0.31447126
29	43,747,765	*rs42190085*	0.61498554	0.29925040	0.01867855	0.69135855	0.15545894	0.15423447
29	43,749,527	*ss86299346*	0.23117133	0.28797421	0.03062952	0.39580652	0.14410590	0.32099723
29	43,777,249	*ss86299989*	0.05204709	1.23855542	0.04279939	0.30596175	0.00862948	0.12086964
29	43,826,144	*rs42191289*	0.08355832	1.07275064	0.46344422	0.17992963	0.60679991	2.10421872
29	43,839,783	*ss86336460*	0.65687172	1.57750548	0.42813638	0.60240929	0.27736123	2.57848708
29	43,914,923	*ss86335514*	5.41309793	1.21043891	1.29638005	3.23934367	0.57977131	3.48219782
29	44,000,728	*rs42191319*	0.28733855	0.00041707	0.43862251	0.33148269	0.35713837	0.11318397
29	44,029,526	*rs42192038*	1.20751437	0.61860399	0.15163110	0.76352207	0.29883743	1.50891107
29	44,042,363	*rs42192064*	3.78983596	2.11305517	0.81294077	0.43141451	0.07967046	6.51065616
29	44,049,244	*rs42192077*	0.53544650	0.28049136	1.11635461	0.09636135	0.00017937	0.06853338
29	44,050,471	*ss86284058*	1.31634950	0.18165119	2.73155940	0.77897574	0.08559228	0.55261272
29	44,051,567	*rs42192079*	0.43791985	0.18793165	0.94534508	0.09995925	0.00801219	0.08018721
29	44,053,733	*rs42192083*	0.40600605	0.26290107	0.98615509	0.07197118	0.03036354	0.09347804
29	44,054,901	*rs42192084*	0.23271677	0.19155845	0.43966180	0.42005085	0.10259460	0.34485314
29	44,058,688	*rs42192090*	0.63374532	1.03088313	0.26325766	2.16293094	0.44993328	0.45997855
29	44,060,410	*rs42192096*	0.58111065	1.09484368	0.44353513	1.43528346	0.29247259	0.79125781
29	44,062,694	*rs42192100*	0.55597264	1.10606032	0.43772073	1.27617242	0.24952277	0.72058476
29	44,063,938	*rs17872078*	11.06385692	4.73157664	3.95490039	3.60275558	0.12298021	3.56044339
29	44,067,234	*rs17872093*	0.49119246	1.09484368	0.61056779	1.43528346	0.24952277	0.82128250
29	44,067,796	*rs17871984*	9.12386593	4.17029373	6.17311920	1.38841165	0.33534977	1.65236722
29	44,068,143	*rs17870631*	15.02478285	6.53020157	4.79267429	5.02153497	0.01743977	5.61780734
29	44,068,346	*rs17870628*	8.02478258	3.72104979	5.03083483	1.69430079	0.23008326	2.29019068
29	44,068,445	*rs17870626*	14.02591772	5.99882130	4.56681868	4.87245328	0.10332268	5.32147410
29	44,068,519	*rs17872010*	13.92040678	6.23558901	4.32611748	5.02153497	0.01743977	5.22609254
29	44,068,580	*rs17872004*	14.69756940	6.53020157	4.70900007	4.95672805	0.04699462	5.33363070
29	44,068,812	*rs17872003*	14.52861819	6.54890094	4.68559191	5.23726316	0.05731284	5.26903465
29	44,069,063	*rs17812000*	15.01318351	9.70325035	3.86955288	5.02153497	0.01743977	5.34387541
29	44,069,177	*rs17872006*	12.16297032	6.95858004	3.95278603	3.63333825	0.20827835	4.93570623
29	44,070,713	*rs42192103*	15.25158225	5.57498348	5.51973138	5.66567676	0.18467504	5.99674646
29	44,070,881	*rs42192105*	3.44303003	1.04085226	3.19416028	0.16828075	0.05476708	0.95464665
29	44,071,034	*rs42192107*	3.60877221	1.14058147	3.31494388	0.42816961	0.05476708	0.59604337
29	44,071,135	*rs42192108*	0.84761227	0.11400826	0.24937838	0.31296813	1.21868023	0.05172524
29	44,071,593	*rs42192109*	1.34891868	2.04739447	0.13589882	2.48998697	0.46197675	0.93864158
29	44,085,642	*rs17871051*	5.52314725	6.47497947	0.90205454	1.69543379	0.89215774	2.61559871
29	44,085,769	*rs17871058*	7.11609711	3.39328007	0.60316732	4.37345894	2.84572845	2.88941271
29	44,087,205	*rs17872032*	4.07412817	2.69647902	0.11119448	2.27449768	0.61567777	2.27417512
29	44,087,356	*rs17872033*	4.80268257	5.73921171	0.86225702	1.56598606	1.12117208	1.91960350
29	44,087,629	*rs17872050*	7.27411721	3.95801125	0.58442547	4.49008758	3.23458930	2.59790176
29	44,087,858	*rs17872151*	1.91592723	0.05811805	1.11957708	0.90851090	0.28340516	0.74334865

29	44,088,897	*rs17870847*	6.98857664	3.53198021	0.49906676	4.69114559	3.16712717	2.42102017
29	44,110,295	*rs42192119*	0.24763846	0.11219104	0.09233846	0.61056832	0.36911136	0.14787609
29	44,119,671	*rs42195143*	0.13149919	0.33349792	0.99637011	0.05862776	0.10126358	0.17576138
29	44,122,272	*rs42194216*	0.44091580	0.18173824	0.76346807	0.27321828	0.10568910	0.00595621
29	44,125,747	*rs42194178*	0.47074672	0.24535880	0.89696110	0.27137387	0.10568910	0.00595621
29	44,130,887	*rs42194132*	0.34790036	0.24535880	0.80201702	0.27822368	0.10568910	0.14103651
29	44,154,126	*rs42193349*	0.73134565	1.60354632	1.02285973	0.22531657	0.16005057	0.43020523
29	44,172,614	*ss117965984*	0.89921288	0.00903521	0.79790059	0.48422659	0.20438421	0.83691045
29	44,196,154	*ss86318958*	0.17826692	0.83275480	0.79139179	0.31733155	0.09584821	0.09352201
29	44,208,978	*rs29003633*	0.72332983	4.82095682	0.01810898	0.13778251	0.05217681	0.29638830
29	44,223,148	*ss86323783*	1.87225920	3.93233393	0.04523253	1.83618667	0.67743646	0.14198146
29	44,243,444	*ss86313099*	0.08257010	1.92540086	1.69616348	0.95541644	0.08870579	0.24639965
29	44,325,408	*ss86292140*	5.67467249	5.33541800	1.08931228	1.55484928	0.44966064	2.51916267
29	44,372,611	*ss86329852*	0.53162591	0.02803790	0.48418639	1.23731403	0.80255075	0.90485283
29	44,395,075	*ss86333994*	2.06219114	1.66817727	1.16265211	0.06130758	0.18184149	2.06865498
29	44,416,282	*rs43709648*	5.68390548	4.77448860	4.22466506	1.33513815	0.06867912	0.52090920
29	44,546,564	*ss86288185*	1.62442034	1.35229526	1.25855827	0.71522273	0.04494773	0.39605969
29	44,585,782	*ss86341172*	0.93033545	0.89359393	0.51199420	1.19185100	0.31208265	0.27979050
29	44,628,137	*rs41600300*	0.10219117	1.45782122	0.41298898	0.31552270	0.70959496	0.63515653
29	44,649,908	*ss86337530*	0.04163328	0.09909412	1.09696773	0.27955691	0.09828177	0.87398116
29	44,740,917	*ss86334185*	1.17528419	1.72921586	1.09441063	0.35244420	0.28055154	0.22148194
29	44,807,928	*ss117965824*	0.24486922	1.68461918	1.22415017	0.02552680	0.03251072	0.15375166
29	44,853,970	*rs42192429*	0.04285861	2.70896169	0.24443504	0.96548290	0.25802019	1.05292526
29	44,900,940	*rs43706228*	1.16255448	4.47829875	0.12815280	2.96298435	0.05421330	0.16986484
29	44,969,518	*ss86337154*	0.75559117	0.31551240	0.38456438	0.97456211	0.29136167	0.29457028
29	44,979,377	*ss86338214*	0.16929778	0.41243332	0.34406199	0.23475380	0.09033549	0.48360841
29	44,999,264	*ss86310727*	2.47136644	1.33314498	0.07862254	1.19352282	1.15758380	1.89272860
29	45,023,665	*ss86338763*	0.50154984	0.31551240	1.02362911	0.82814950	0.29136167	0.22855959
29	45,102,557	*ss86332221*	2.80208621	1.39414911	0.10735358	3.81708940	0.08121695	2.01548437
29	45,129,099	*ss86335405*	1.92518407	1.91040532	0.55154806	1.87871179	0.10445101	0.35823047
29	45,187,114	*ss86295760*	0.48656271	1.77102946	0.30303839	0.06520406	0.15318487	0.07669521
29	45,287,502	*ss86312485*	1.47288059	1.04081145	0.13075897	2.75606820	0.42122552	0.08683296
29	45,326,585	*rs42198683*	0.17928117	0.34149476	0.64650443	1.93008045	0.09554951	0.37980161
29	45,367,095	*ss86322638*	0.41840731	0.41923223	1.08477513	0.17936027	0.38174958	0.67379779
29	45,458,280	*rs43706176*	0.31849023	1.14656944	0.18898358	0.07227556	0.27896857	0.00510871
29	45,482,143	*rs29025626*	1.37928192	3.32818270	0.04864044	0.38112107	1.95322650	0.38976296
29	45,530,264	*ss86341375*	0.25925427	0.17470233	0.04224125	0.01600602	0.49028244	0.80895685

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and green for the with

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relationship matrix.

[6]$-\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are shaded in red.

[7]$-\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum values are shade

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP block centered

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

						-log$_{10}$(P)HSE[7]		
BTA	POS[1]	SNP ID[2]	H-All Breeds	H-Angus	H-Hereford	H-Charolais	H-Limousin	H-Simmental
7	97,151,592	*rs41656985*						
7	97,261,052	*rs41656987*						
7	97,372,656	*rs41570922*						
7	97,393,157	*rs41615915*						
7	97,430,691	*ss86295638*	0.26508076	0.22716139	0.35490286	0.11939695	1.17950014	0.05611460
7	97,501,859	*ss86310801*	0.81800928	0.07156966	0.33609847	0.06345397	2.15235804	0.09168065
7	97,529,872	*ss61472319*	1.98049919	0.14371942	1.39259947	0.12678032	1.29152534	0.15902671
7	97,691,853	*ss86290016*	1.38106720	0.03262946	1.44345770	0.06604644	1.08465456	0.00273854
7	97,772,240	*ss86312419*	1.11696273	0.03704186	0.59346134	0.01414687	1.48842612	0.51559835
7	97,861,341	*rs41593284*	1.07333880	0.18884830	1.54612811	1.28697105	1.94622343	0.70741950
7	97,898,940	*rs41593281*	1.20710768	0.21395773	0.35285888	0.56983555	0.84014096	0.97571611
7	97,961,659	*ss117969141*	1.56513141	0.58260066	1.18631024	0.80927320	1.45814808	0.69798479
7	98,013,150	*ss117968909*	1.94109221	0.42866082	1.70014361	1.07709074	1.53017736	0.54579568
7	98,173,299	*ss86290989*	5.19485373	0.21666189	3.08995548	0.57537080	0.40169634	1.26846310
7	98,194,828	*rs41658549*	7.19312845	1.45022845	3.28674164	0.88346307	0.94186821	1.09107705
7	98,254,815	*rs41658542*	7.30762392	1.20874235	3.86521461	0.64348316	1.16137417	1.44864297
7	98,375,640	*ss86329349*	5.20735013	0.69984802	3.62626557	0.21261409	0.99651092	1.49969468
7	98,495,888	*rs43529872*	8.78946851	2.75028009	3.88742490	3.77219492	1.18671624	0.67066205
7	98,498,047	*ss86321563*	5.26395768	0.95003489	3.26823256	1.24059094	0.59144138	0.50885778
7	98,538,952	*rs41660170*	5.75844597	1.24611419	4.18746267	4.02764991	0.34395397	1.25539145
7	98,566,391	*ss117962527*	5.29372661	0.80510588	4.56286232	2.37126445	0.89744762	0.24031325
7	98,579,574	*rs41255587*	3.98897683	0.52039442	3.44498563	2.02857191	0.63931022	0.40299644
7	98,635,208	*ss86300200*	2.32088832	0.36484788	3.13453957	1.47339982	1.97169891	0.04134551
7	98,646,770	*rs41596489*	3.35672116	0.12551053	2.35292792	0.83513958	0.61692184	0.74500295
7	98,680,293	*ss86315737*	1.46829182	0.45527887	1.11997405	0.72275624	1.52410372	0.77676452
7	98,726,055	*rs29018251*	2.68450826	0.00446483	2.59819051	1.64736930	0.04882888	1.21792070
7	98,757,265	*ss86303738*	0.25145766	0.01037767	1.07605607	0.11879893	0.05675627	0.52793539
7	98,820,742	*ss86324113*	1.27277626	0.00316008	0.87855733	0.82996525	0.16650701	0.07170139
7	98,887,313	*rs41568595*	1.04874555	0.24055696	1.92106638	2.27907223	0.25832342	0.34138781
7	98,907,404	*ss86291843*	0.12659421	0.04140937	0.47312626	1.08738269	0.30143055	0.17518428
7	98,974,456	*ss86339659*	0.35618278	0.11996119	0.43000780	3.20102208	1.59395272	0.16889318
7	99,024,444	*ss117968912*	1.38169398	0.46449100	2.42800812	3.82249522	0.33963017	0.03566803
7	99,085,299	*rs41590403*	1.41246704	0.22315877	2.07804148	1.22225322	0.25108351	0.12469519
7	99,130,598	*ss86333606*	0.46025697	0.00984278	1.09712190	0.87025315	0.99486135	0.02418621
7	99,178,748	*rs41568774*	0.27207244	0.07530685	0.40169694	1.03480593	0.17213830	0.08893838
7	99,215,474	*ss86324013*	1.54040285	0.23635459	1.69528036	0.45088169	0.01317582	0.20992227
7	99,344,820	*rs41622872*	0.77418023	1.10702407	0.64002365	0.03192407	0.45514191	0.44536115
7	99,399,852	*ss117968895*	0.02699322	0.01194669	0.05783008	0.01770490	0.62311139	0.00584030
7	99,492,904	*ss86296856*	0.67099476	0.03420171	0.23136372	0.31714738	0.56405439	0.21482810
7	99,635,841	*ss86339853*	0.26382175	0.06423947	0.07232531	0.24511858	1.09094161	0.22922627
7	99,687,614	*rs41657025*						
7	99,845,133	*rs41624339*						
7	99,919,908	*ss86339607*						
7	100,015,468	*ss86310226*						
29	42,406,544	*ss86319674*						
29	42,455,680	*ss117974470*						
29	42,620,218	*rs42189770*						
29	42,651,294	*rs43706142*						
29	42,696,595	*rs42189112*	0.30906697	0.88607575	0.02123152	0.39494132	0.15097430	0.23355190
29	42,749,808	*rs29020063*	0.60218769	0.98996223	0.03249730	0.59290246	0.34019608	1.19943101
29	42,842,353	*ss117974486*	1.13550193	0.65699706	0.47372237	0.02181479	0.08405313	1.12277303
29	42,897,144	*ss86322358*	0.71512224	2.11448646	0.53312529	0.14369412	0.21209756	0.88613922

29	43,006,000	*ss86339964*	0.73271265	2.41188485	0.33960364	0.08529153	0.77321440	1.56473566
29	43,043,207	*ss86341572*	0.82246094	2.32985985	0.11124371	0.09751926	0.15356810	1.43976778
29	43,108,445	*ss86337140*	0.81896949	2.33109058	0.00285613	0.00222270	0.18021498	1.69495979
29	43,129,250	*ss86337549*	1.63994035	4.20422145	0.06100995	0.16876456	0.03220266	0.93963329
29	43,189,370	*ss86319044*	1.18301713	1.19782548	0.86122390	0.01091282	0.23608231	0.49359785
29	43,224,753	*rs29013208*	2.37813436	3.18593611	1.67880213	0.01106032	0.11811475	0.61501851
29	43,269,744	*ss86282762*	3.86475938	3.82149385	2.26416192	0.14418999	0.55321311	0.92959597
29	43,304,256	*rs29024708*	1.24577534	1.55404902	0.83388990	0.16568222	0.13932080	1.35982228
29	43,328,607	*ss86295061*	1.62487690	2.40837626	0.42667436	1.64421339	0.02121940	1.33710261
29	43,429,511	*ss86318094*	2.12572529	3.80842344	1.28881993	0.95480642	0.02553625	1.44611500
29	43,466,342	*ss86310741*	0.71555522	1.12116750	0.88703677	0.33284474	0.00270686	0.56692846
29	43,498,073	*ss86338800*	1.45812150	2.95862003	0.90383764	0.85347409	0.41198322	0.31775444
29	43,611,640	*ss86298040*	1.71738830	1.49905151	0.65021301	0.56840134	0.58927359	0.81617442
29	43,652,252	*ss86327310*	1.85247447	2.72293599	0.38704847	1.21836700	0.46366774	1.06027271
29	43,686,401	*ss86325323*	2.85471722	5.50057900	0.89673711	1.10064931	0.00287942	2.04317052
29	43,709,769	*ss86290081*	2.37660557	7.30961397	0.69453568	0.90919636	0.76372755	2.56351112
29	43,747,765	*rs42190085*	1.57659695	2.45959885	0.82975654	0.08757620	0.69431647	2.26028050
29	43,749,527	*ss86299346*	1.17290269	1.12334737	0.87827269	0.58774448	0.69851826	1.38948401
29	43,777,249	*ss86299989*	3.02787309	1.34862602	1.70160346	0.33254679	1.47845730	1.58800258
29	43,826,144	*rs42191289*	5.32853039	1.18426692	3.31864667	0.80798556	0.11909686	1.37750458
29	43,839,783	*ss86336460*	0.34757971	1.24877665	0.88353443	0.25582816	0.10286128	0.42109271
29	43,914,923	*ss86335514*	0.41546339	0.90700286	0.13421452	0.59111298	0.14605836	0.88599779
29	44,000,728	*rs42191319*	0.82185269	0.04755089	0.49823042	0.84353654	0.13510732	0.83505751
29	44,029,526	*rs42192038*	0.50880964	0.31129890	0.27972788	0.86600833	0.26925594	0.44131506
29	44,042,363	*rs42192064*	0.13658017	0.11580871	0.72905363	0.71583709	0.01905937	0.08194063
29	44,049,244	*rs42192077*	1.35767164	1.22634702	0.85886097	1.46652883	0.02509769	0.70198908
29	44,050,471	*ss86284058*	1.61646995	1.67349815	0.67683014	0.48665107	0.28414395	1.97858819
29	44,051,567	*rs42192079*	3.30712727	1.42085559	2.44795993	0.82580793	0.00975328	2.86690989
29	44,053,733	*rs42192083*	3.39158339	2.38296426	1.30292318	0.94212815	0.21402334	3.00111352
29	44,054,901	*rs42192084*	11.49369842	3.55621855	5.21648679	3.10996361	0.23084442	1.99917782
29	44,058,688	*rs42192090*	7.88594584	1.80903613	5.70470916	3.31341794	0.09513478	2.83102329
29	44,060,410	*rs42192096*	0.12986183	1.46336669	2.16083744	1.23070016	0.45062150	0.15558495
29	44,062,694	*rs42192100*	12.27238874	2.41838262	6.74301670	1.67412867	0.48273454	1.60991865
29	44,063,938	*rs17872078*	12.23589788	2.29047402	5.87511925	2.49050918	0.10200335	2.19095222
29	44,067,234	*rs17872093*	16.88269453	6.57015459	5.61324508	3.26121021	0.26036723	4.51981527
29	44,067,796	*rs17871984*	18.42738682	5.84412338	5.71691132	4.08482900	0.27637483	4.20909177
29	44,068,143	*rs17870631*	18.39968289	6.37524252	5.45793276	4.05568887	0.23002304	4.03478613
29	44,068,346	*rs17870628*	12.38241270	5.04806672	2.70913095	4.10912997	0.24068611	2.93239801
29	44,068,445	*rs17870626*	13.82885695	9.34358563	3.53168518	4.15858213	0.32596470	3.28779936
29	44,068,519	*rs17872010*	15.25910115	9.89889309	5.93905737	4.63045660	1.24106440	3.82501971
29	44,068,580	*rs17872004*	6.47969623	5.68172394	3.81874178	0.49614568	0.25001902	1.82874448
29	44,068,812	*rs17872003*	2.05963582	2.46398596	1.24572801	1.47993935	0.15068095	0.56014166
29	44,069,063	*rs17812000*	9.77853894	7.47435434	2.39643816	2.79419971	0.12049838	3.66924718
29	44,069,177	*rs17872006*	13.46353251	7.96050207	3.86770851	4.29375576	0.88025979	3.88562500
29	44,070,713	*rs42192103*	11.55151331	6.44427023	4.27234495	4.12354576	0.95747805	2.99347063
29	44,070,881	*rs42192105*	13.20467660	6.97082267	4.74847929	5.85379933	1.34839067	2.63128615
29	44,071,034	*rs42192107*	12.98510976	6.43286369	4.17187350	5.64602414	0.28760212	2.92776017
29	44,071,135	*rs42192108*	2.37657109	2.85669709	1.57339654	0.99186327	0.28553372	0.51775051
29	44,071,593	*rs42192109*	2.43465244	2.35156168	1.72365835	1.06696035	0.56643274	0.11445303
29	44,085,642	*rs17871051*	2.22122719	3.74051691	0.20554006	3.10807112	0.97276859	2.13239684
29	44,085,769	*rs17871058*	6.61208861	8.38064456	3.00878845	3.07580730	1.26456466	2.23802562
29	44,087,205	*rs17872032*	6.40228903	7.70690103	1.37392140	1.67479791	1.32025609	2.25287170
29	44,087,356	*rs17872033*	2.71654734	2.41023275	0.82639683	0.30604784	1.49210014	0.98590337
29	44,087,629	*rs17872050*	2.98168563	1.19410286	1.05055383	1.77522158	0.83669683	1.28942592
29	44,087,858	*rs17872151*	1.93894476	1.14413413	1.96526756	0.39565199	0.29177155	0.62766408

29	44,088,897	*rs17870847*	0.16133199	0.79403792	0.21583410	0.49005619	0.02166887	0.00111337
29	44,110,295	*rs42192119*	1.60735942	0.87925948	0.21436998	1.12419681	0.03163904	1.06791215
29	44,119,671	*rs42195143*	1.22792288	0.54340136	0.97473257	0.20362366	0.10037664	0.29155327
29	44,122,272	*rs42194216*	2.51318370	0.47540070	1.04175576	2.70682242	0.14208366	1.16366448
29	44,125,747	*rs42194178*	2.23965847	0.35775641	0.18928124	2.96180470	0.07248796	1.32894979
29	44,130,887	*rs42194132*	1.81890816	0.46168104	0.39822265	1.67786057	0.29121497	1.17182571
29	44,154,126	*rs42193349*	0.65076323	3.31740232	0.02064049	0.26745156	0.31157124	0.36263333
29	44,172,614	*ss117965984*	0.23199661	3.28778318	1.02199034	2.44002739	0.05228876	0.36745166
29	44,196,154	*ss86318958*	1.81161647	1.75877838	2.16745327	0.19969184	0.01874044	1.57245625
29	44,208,978	*rs29003633*	1.87290255	3.00026737	0.70748339	0.12248651	0.01088652	1.10235697
29	44,223,148	*ss86323783*	1.54925700	0.56620010	2.55633328	0.59153503	0.02959121	1.37000248
29	44,243,444	*ss86313099*	1.65698290	0.89625423	2.40467619	0.64371127	0.20064084	0.76500188
29	44,325,408	*ss86292140*	6.82799864	1.97015854	3.23951326	2.38246215	0.32381463	0.80251350
29	44,372,611	*ss86329852*	1.44683209	0.19968322	2.94240217	0.12341834	0.54213787	0.50892430
29	44,395,075	*ss86333994*	1.43940004	0.57500362	2.98266063	0.19138583	0.46385971	0.49592585
29	44,416,282	*rs43709648*	1.56049570	2.54501513	1.06492009	0.63239930	0.01669722	0.90088312
29	44,546,564	*ss86288185*	5.32381518	3.01422973	3.84893761	0.53942642	0.00462038	1.36466524
29	44,585,782	*ss86341172*	2.46757085	1.31429916	0.75921234	0.64833951	0.01279982	0.53388457
29	44,628,137	*rs41600300*	0.59487472	2.14009510	0.49302374	0.15268886	0.55836508	0.91422243
29	44,649,908	*ss86337530*	1.01897824	1.15277044	0.96862457	1.32901788	0.30646495	1.12382422
29	44,740,917	*ss86334185*	0.48680305	2.69382778	0.26618189	0.25735165	0.12919985	0.70970398
29	44,807,928	*ss117965824*	2.15392065	3.50921540	0.05121356	2.63424357	0.08061088	0.55089100
29	44,853,970	*rs42192429*	2.31724705	5.76063374	0.77973760	0.17127986	0.80095841	0.88638095
29	44,900,940	*rs43706228*	2.19610799	3.93534502	1.11862283	0.39006681	0.76834606	0.28628755
29	44,969,518	*ss86337154*	1.94685789	5.32150326	0.59049892	1.21396124	0.34880684	0.04453270
29	44,979,377	*ss86338214*	0.62499693	1.76815948	0.83021256	0.35757153	0.24917828	0.37576807
29	44,999,264	*ss86310727*	0.58311707	0.05002567	0.40984010	1.24270857	0.16974211	0.20788783
29	45,023,665	*ss86338763*	1.10742450	2.82842226	0.54096063	3.35054933	0.06487693	0.47992127
29	45,102,557	*ss86332221*	0.70729646	1.30554383	0.40632859	3.33952068	0.20370789	0.65698242
29	45,129,099	*ss86335405*	0.08011029	0.56628152	0.17913265	1.47136413	0.10457292	0.03010530
29	45,187,114	*ss86295760*	3.90874839	0.47612537	3.19993420	1.36504297	0.10578806	0.13928507
29	45,287,502	*ss86312485*	1.62763739	2.77694631	2.25493961	0.77715979	0.15892100	0.81196521
29	45,326,585	*rs42198683*	1.84232573	2.43676900	2.15095695	1.04701284	0.35084659	0.49732541
29	45,367,095	*ss86322638*						
29	45,458,280	*rs43706176*						
29	45,482,143	*rs29025626*						
29	45,530,264	*ss86341375*						

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and green for the with

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relationship matrix.

[6]-$\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are shaded in red.

[7]-$\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum values are shade

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP block centered

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

						No. Haplotypes[8]		
BTA	POS[1]	SNP ID[2]	All Breeds	Angus	Hereford	Charolais	Limousin	Simmental
7	97,151,592	*rs41656985*						
7	97,261,052	*rs41656987*						
7	97,372,656	*rs41570922*						
7	97,393,157	*rs41615915*						
7	97,430,691	*ss86295638*	8 (2.97)	8 (2.20)	6 (2.65)	8 (3.79)	7 (3.73)	8 (2.67)
7	97,501,859	*ss86310801*	8 (3.65)	8 (3.13)	6 (2.76)	8 (4.47)	6 (4.83)	7 (3.52)
7	97,529,872	*ss61472319*	8 (3.73)	8 (3.05)	7 (3.00)	7 (3.84)	7 (4.44)	8 (3.78)
7	97,691,853	*ss86290016*	7 (3.89)	7 (3.07)	6 (2.99)	7 (4.04)	7 (4.55)	7 (4.19)
7	97,772,240	*ss86312419*	7 (3.57)	7 (2.77)	7 (2.85)	7 (4.57)	7 (4.61)	7 (3.72)
7	97,861,341	*rs41593284*	7 (3.04)	7 (2.07)	6 (2.42)	7 (3.99)	7 (5.29)	7 (3.18)
7	97,898,940	*rs41593281*	6 (3.46)	6 (2.90)	6 (2.45)	6 (4.16)	6 (4.23)	6 (4.06)
7	97,961,659	*ss117969141*	6 (3.22)	6 (3.22)	5 (1.95)	6 (3.62)	6 (3.74)	6 (4.00)
7	98,013,150	*ss117968909*	7 (3.41)	6 (3.31)	5 (2.07)	7 (4.01)	6 (3.86)	6 (4.13)
7	98,173,299	*ss86290989*	8 (4.77)	6 (3.82)	7 (3.56)	7 (4.07)	6 (4.22)	8 (4.02)
7	98,194,828	*rs41658549*	8 (4.43)	6 (3.27)	7 (3.54)	6 (3.95)	6 (3.97)	8 (3.53)
7	98,254,815	*rs41658542*	8 (4.34)	7 (3.52)	7 (3.42)	6 (4.03)	7 (4.29)	8 (3.65)
7	98,375,640	*ss86329349*	8 (4.18)	7 (3.20)	7 (3.63)	7 (3.42)	7 (3.84)	8 (3.60)
7	98,495,888	*rs43529872*	9 (4.21)	8 (3.39)	8 (3.34)	7 (3.38)	8 (3.95)	9 (3.46)
7	98,498,047	*ss86321563*	9 (5.03)	8 (3.93)	8 (3.79)	8 (4.01)	8 (4.51)	9 (3.92)
7	98,538,952	*rs41660170*	8 (4.20)	8 (3.58)	7 (2.97)	8 (3.90)	7 (3.46)	8 (4.00)
7	98,566,391	*ss117962527*	8 (3.78)	8 (3.22)	6 (2.79)	7 (3.61)	6 (3.01)	7 (4.49)
7	98,579,574	*rs41255587*	8 (4.10)	8 (2.92)	6 (3.20)	7 (3.98)	6 (3.23)	7 (4.40)
7	98,635,208	*ss86300200*	8 (3.25)	8 (3.00)	6 (2.70)	7 (3.35)	6 (2.89)	7 (3.34)
7	98,646,770	*rs41596489*	9 (3.46)	9 (3.75)	6 (2.50)	7 (4.01)	6 (3.07)	7 (3.17)
7	98,680,293	*ss86315737*	8 (3.54)	8 (3.48)	6 (2.82)	7 (4.08)	7 (3.31)	7 (3.38)
7	98,726,055	*rs29018251*	8 (3.54)	7 (3.63)	7 (2.66)	7 (3.66)	7 (3.73)	8 (3.41)
7	98,757,265	*ss86303738*	7 (3.38)	6 (4.02)	5 (2.52)	7 (3.81)	6 (3.12)	7 (3.29)
7	98,820,742	*ss86324113*	7 (4.01)	7 (3.97)	7 (2.93)	6 (3.86)	6 (3.56)	7 (3.45)
7	98,887,313	*rs41568595*	8 (4.84)	7 (4.79)	7 (4.12)	7 (4.98)	7 (3.89)	8 (4.53)
7	98,907,404	*ss86291843*	7 (4.35)	6 (3.78)	6 (3.51)	7 (4.39)	7 (3.50)	7 (4.70)
7	98,974,456	*ss86339659*	7 (3.79)	7 (3.93)	7 (3.15)	7 (4.04)	7 (2.91)	7 (3.89)
7	99,024,444	*ss117968912*	7 (3.58)	7 (3.19)	6 (3.30)	7 (3.37)	6 (3.41)	6 (3.47)
7	99,085,299	*rs41590403*	7 (3.97)	6 (3.54)	6 (3.77)	6 (3.61)	6 (3.06)	7 (4.21)
7	99,130,598	*ss86333606*	7 (3.89)	6 (3.51)	6 (3.62)	6 (3.70)	6 (3.64)	7 (4.08)
7	99,178,748	*rs41568774*	9 (4.42)	7 (4.37)	6 (3.60)	6 (3.92)	6 (3.95)	8 (4.52)
7	99,215,474	*ss86324013*	9 (4.14)	7 (4.41)	8 (3.25)	7 (4.05)	7 (3.59)	9 (4.71)
7	99,344,820	*rs41622872*	8 (3.77)	6 (4.34)	8 (2.69)	7 (3.64)	7 (3.45)	8 (4.05)
7	99,399,852	*ss117968895*	9 (3.71)	7 (3.58)	8 (3.08)	6 (3.31)	7 (3.36)	7 (4.11)
7	99,492,904	*ss86296856*	8 (4.87)	7 (4.59)	7 (3.06)	6 (4.06)	7 (3.43)	7 (4.87)
7	99,635,841	*ss86339853*	9 (4.28)	7 (4.79)	7 (2.39)	7 (4.52)	8 (3.65)	7 (4.39)
7	99,687,614	*rs41657025*						
7	99,845,133	*rs41624339*						
7	99,919,908	*ss86339607*						
7	100,015,468	*ss86310226*						
29	42,406,544	*ss86319674*						
29	42,455,680	*ss117974470*						
29	42,620,218	*rs42189770*						
29	42,651,294	*rs43706142*						
29	42,696,595	*rs42189112*	7 (3.96)	7 (3.83)	7 (3.14)	7 (3.75)	7 (4.05)	7 (3.91)
29	42,749,808	*rs29020063*	8 (5.15)	8 (4.64)	8 (4.10)	8 (4.93)	8 (4.67)	8 (5.59)
29	42,842,353	*ss117974486*	9 (4.30)	8 (3.29)	9 (4.15)	8 (3.99)	8 (4.62)	9 (4.81)
29	42,897,144	*ss86322358*	9 (4.91)	9 (3.94)	9 (3.93)	9 (4.52)	9 (5.42)	9 (4.80)

29	43,006,000	*ss86339964*	10 (3.56)	9 (3.28)	9 (3.08)	9 (2.93)	9 (5.55)	10 (4.31)
29	43,043,207	*ss86341572*	9 (3.80)	8 (3.87)	8 (2.50)	8 (3.66)	8 (4.67)	9 (4.61)
29	43,108,445	*ss86337140*	10 (2.88)	7 (2.57)	7 (2.26)	7 (2.72)	7 (4.72)	10 (3.45)
29	43,129,250	*ss86337549*	9 (2.36)	7 (2.21)	7 (1.92)	7 (2.38)	6 (3.65)	9 (2.67)
29	43,189,370	*ss86319044*	8 (2.25)	7 (2.21)	7 (1.63)	7 (2.50)	7 (3.07)	8 (3.07)
29	43,224,753	*rs29013208*	8 (2.92)	6 (2.71)	7 (2.68)	7 (2.61)	6 (3.06)	8 (3.35)
29	43,269,744	*ss86282762*	7 (2.83)	5 (2.57)	6 (2.86)	6 (2.66)	6 (1.80)	7 (3.23)
29	43,304,256	*rs29024708*	7 (3.26)	5 (3.05)	7 (3.04)	6 (3.16)	5 (2.25)	7 (3.62)
29	43,328,607	*ss86295061*	7 (4.00)	7 (3.65)	5 (3.71)	6 (4.22)	5 (3.17)	7 (3.83)
29	43,429,511	*ss86318094*	8 (4.72)	8 (4.52)	6 (3.85)	7 (5.13)	6 (3.17)	8 (4.74)
29	43,466,342	*ss86310741*	8 (5.38)	7 (4.56)	7 (5.75)	6 (5.46)	7 (3.18)	8 (5.07)
29	43,498,073	*ss86338800*	8 (6.21)	8 (6.12)	8 (6.03)	7 (6.12)	7 (3.37)	8 (6.18)
29	43,611,640	*ss86298040*	9 (6.18)	8 (5.89)	8 (5.38)	9 (6.26)	7 (3.47)	8 (6.39)
29	43,652,252	*ss86327310*	7 (5.32)	7 (6.32)	7 (3.74)	7 (5.34)	7 (3.61)	7 (6.21)
29	43,686,401	*ss86325323*	7 (5.06)	6 (4.83)	6 (4.88)	7 (5.03)	6 (4.20)	6 (4.67)
29	43,709,769	*ss86290081*	7 (4.64)	6 (4.69)	6 (3.82)	7 (4.94)	6 (4.33)	6 (4.83)
29	43,747,765	*rs42190085*	7 (4.82)	7 (5.00)	7 (2.85)	7 (5.67)	7 (4.82)	7 (5.78)
29	43,749,527	*ss86299346*	7 (4.47)	6 (5.42)	6 (2.75)	7 (5.42)	7 (3.53)	7 (5.49)
29	43,777,249	*ss86299989*	6 (4.53)	6 (4.94)	5 (3.06)	6 (4.70)	6 (3.13)	6 (4.50)
29	43,826,144	*rs42191289*	6 (4.42)	6 (4.50)	6 (4.17)	6 (3.93)	6 (3.55)	6 (4.53)
29	43,839,783	*ss86336460*	7 (4.67)	6 (4.35)	7 (4.21)	6 (4.43)	6 (3.70)	7 (4.60)
29	43,914,923	*ss86335514*	8 (4.57)	7 (4.10)	7 (3.53)	7 (4.69)	6 (4.87)	8 (4.86)
29	44,000,728	*rs42191319*	8 (4.52)	7 (4.03)	7 (4.33)	6 (4.39)	6 (4.59)	6 (4.30)
29	44,029,526	*rs42192038*	7 (3.76)	7 (3.19)	7 (3.53)	7 (3.70)	6 (4.11)	7 (3.44)
29	44,042,363	*rs42192064*	7 (3.22)	6 (2.55)	6 (2.95)	5 (3.11)	5 (4.09)	5 (3.43)
29	44,049,244	*rs42192077*	6 (3.30)	5 (2.98)	6 (3.08)	4 (3.34)	4 (3.04)	5 (3.32)
29	44,050,471	*ss86284058*	6 (3.66)	6 (3.10)	6 (3.14)	6 (3.50)	6 (2.36)	6 (3.44)
29	44,051,567	*rs42192079*	6 (3.10)	6 (2.97)	5 (2.85)	5 (3.26)	4 (2.30)	6 (2.95)
29	44,053,733	*rs42192083*	6 (3.14)	6 (2.88)	5 (2.91)	5 (3.30)	4 (3.03)	6 (3.17)
29	44,054,901	*rs42192084*	6 (2.71)	6 (2.42)	5 (2.46)	5 (2.88)	4 (2.29)	6 (2.92)
29	44,058,688	*rs42192090*	5 (2.17)	5 (2.64)	5 (1.68)	5 (2.39)	4 (1.91)	4 (2.24)
29	44,060,410	*rs42192096*	6 (2.07)	4 (2.28)	5 (1.51)	6 (2.39)	5 (2.04)	5 (2.70)
29	44,062,694	*rs42192100*	6 (1.87)	5 (1.62)	6 (1.67)	5 (2.21)	5 (1.63)	6 (2.45)
29	44,063,938	*rs17872078*	7 (3.06)	5 (3.19)	7 (2.19)	5 (3.33)	6 (2.84)	6 (3.61)
29	44,067,234	*rs17872093*	7 (3.22)	6 (2.81)	7 (2.57)	6 (3.80)	6 (2.67)	6 (3.97)
29	44,067,796	*rs17871984*	8 (3.00)	7 (2.79)	8 (2.45)	7 (3.31)	7 (2.14)	7 (4.12)
29	44,068,143	*rs17870631*	9 (2.95)	7 (2.76)	8 (2.45)	7 (3.27)	6 (2.11)	8 (3.78)
29	44,068,346	*rs17870628*	9 (2.09)	7 (2.44)	7 (1.58)	6 (2.29)	5 (1.68)	8 (2.57)
29	44,068,445	*rs17870626*	7 (1.79)	7 (2.34)	6 (1.47)	6 (1.80)	4 (1.56)	6 (1.88)
29	44,068,519	*rs17872010*	7 (2.87)	6 (2.98)	6 (2.39)	7 (3.04)	6 (2.14)	6 (3.35)
29	44,068,580	*rs17872004*	6 (1.85)	6 (2.27)	6 (1.54)	5 (1.78)	6 (1.66)	5 (2.04)
29	44,068,812	*rs17872003*	6 (1.42)	5 (1.52)	6 (1.41)	5 (1.35)	6 (1.28)	6 (1.51)
29	44,069,063	*rs17812000*	7 (1.81)	5 (2.37)	6 (1.55)	5 (1.68)	5 (1.48)	7 (1.94)
29	44,069,177	*rs17872006*	6 (2.40)	5 (2.81)	6 (2.38)	5 (2.40)	6 (1.78)	6 (1.98)
29	44,070,713	*rs42192103*	8 (3.14)	7 (3.26)	7 (2.99)	7 (3.00)	8 (2.16)	8 (2.99)
29	44,070,881	*rs42192105*	9 (4.11)	8 (3.75)	8 (3.22)	8 (4.32)	8 (3.14)	9 (4.12)
29	44,071,034	*rs42192107*	9 (5.26)	8 (4.70)	8 (3.85)	8 (5.55)	8 (4.26)	9 (5.45)
29	44,071,135	*rs42192108*	9 (4.51)	8 (4.05)	7 (3.83)	7 (3.50)	9 (4.44)	8 (4.09)
29	44,071,593	*rs42192109*	8 (3.86)	8 (3.84)	6 (3.54)	7 (3.19)	8 (2.63)	7 (3.44)
29	44,085,642	*rs17871051*	8 (3.97)	8 (3.91)	6 (3.27)	6 (3.65)	7 (3.31)	7 (4.06)
29	44,085,769	*rs17871058*	7 (4.11)	7 (3.61)	6 (3.52)	6 (3.60)	6 (3.90)	6 (4.06)
29	44,087,205	*rs17872032*	7 (2.73)	6 (2.16)	5 (2.41)	6 (2.80)	6 (2.49)	6 (3.11)
29	44,087,356	*rs17872033*	7 (3.33)	7 (2.69)	6 (3.23)	6 (3.11)	6 (3.69)	7 (3.57)
29	44,087,629	*rs17872050*	7 (3.16)	6 (3.00)	6 (2.79)	6 (3.32)	5 (3.73)	7 (3.14)
29	44,087,858	*rs17872151*	7 (2.86)	7 (2.96)	6 (2.69)	6 (2.88)	5 (3.20)	7 (2.69)

29	44,088,897	*rs17870847*	7 (3.41)	6 (2.81)	6 (3.30)	6 (3.61)	6 (3.93)	7 (3.11)	
29	44,110,295	*rs42192119*	6 (3.29)	6 (2.70)	5 (2.96)	5 (3.80)	5 (3.73)	6 (3.14)	
29	44,119,671	*rs42195143*	6 (2.73)	5 (2.50)	5 (2.91)	5 (2.66)	5 (3.19)	6 (2.33)	
29	44,122,272	*rs42194216*	6 (3.40)	5 (2.63)	6 (3.39)	6 (3.36)	6 (3.65)	6 (3.20)	
29	44,125,747	*rs42194178*	6 (3.53)	6 (2.80)	6 (3.64)	6 (3.54)	6 (3.56)	6 (3.22)	
29	44,130,887	*rs42194132*	7 (3.30)	5 (2.59)	5 (3.65)	6 (3.38)	5 (3.42)	7 (3.05)	
29	44,154,126	*rs42193349*	7 (3.43)	6 (2.85)	6 (3.07)	7 (3.84)	6 (3.38)	7 (3.97)	
29	44,172,614	*ss117965984*	7 (3.38)	5 (2.73)	5 (3.23)	7 (3.34)	6 (2.57)	6 (3.61)	
29	44,196,154	*ss86318958*	7 (3.43)	5 (3.27)	5 (3.29)	6 (3.29)	6 (2.81)	6 (3.56)	
29	44,208,978	*rs29003633*	8 (3.58)	6 (3.65)	6 (3.21)	7 (3.24)	7 (3.19)	6 (3.63)	
29	44,223,148	*ss86323783*	8 (3.87)	7 (3.61)	7 (2.87)	7 (3.90)	8 (4.32)	7 (4.22)	
29	44,243,444	*ss86313099*	8 (4.51)	8 (3.85)	8 (3.91)	8 (3.93)	8 (4.86)	8 (4.48)	
29	44,325,408	*ss86292140*	8 (3.88)	8 (2.40)	8 (3.56)	8 (4.31)	8 (4.87)	8 (4.02)	
29	44,372,611	*ss86329852*	8 (3.84)	7 (3.23)	8 (3.51)	7 (4.19)	7 (4.60)	7 (3.80)	
29	44,395,075	*ss86333994*	8 (3.87)	7 (3.25)	8 (3.61)	7 (4.23)	7 (4.71)	7 (3.86)	
29	44,416,282	*rs43709648*	8 (4.31)	7 (3.21)	8 (3.88)	8 (5.07)	7 (4.95)	8 (4.50)	
29	44,546,564	*ss86288185*	8 (4.92)	7 (4.21)	7 (4.75)	8 (5.14)	8 (4.49)	8 (4.64)	
29	44,585,782	*ss86341172*	9 (3.72)	8 (2.79)	8 (4.09)	8 (3.58)	9 (4.63)	9 (3.25)	
29	44,628,137	*rs41600300*	9 (4.29)	8 (3.15)	8 (4.14)	8 (3.57)	9 (4.53)	9 (3.86)	
29	44,649,908	*ss86337530*	8 (4.23)	6 (3.25)	8 (3.98)	7 (4.06)	7 (4.28)	8 (3.60)	
29	44,740,917	*ss86334185*	8 (3.53)	7 (3.16)	7 (2.90)	7 (3.23)	7 (3.91)	8 (3.46)	
29	44,807,928	*ss117965824*	8 (3.56)	8 (2.83)	7 (2.99)	7 (3.54)	7 (4.67)	8 (4.23)	
29	44,853,970	*rs42192429*	7 (4.05)	7 (4.15)	7 (3.07)	7 (4.22)	7 (4.08)	7 (4.47)	
29	44,900,940	*rs43706228*	8 (4.12)	8 (4.04)	7 (3.13)	8 (4.32)	7 (4.58)	8 (4.25)	
29	44,969,518	*ss86337154*	8 (4.45)	8 (4.24)	8 (3.82)	8 (4.46)	7 (4.60)	8 (4.57)	
29	44,979,377	*ss86338214*	7 (4.14)	7 (3.79)	7 (4.21)	7 (3.71)	6 (4.61)	7 (4.08)	
29	44,999,264	*ss86310727*	7 (3.92)	7 (3.51)	7 (2.74)	6 (3.27)	6 (3.90)	7 (4.34)	
29	45,023,665	*ss86338763*	7 (4.03)	6 (3.94)	7 (3.90)	6 (3.19)	6 (4.38)	7 (4.21)	
29	45,102,557	*ss86332221*	7 (3.53)	7 (3.34)	7 (2.88)	7 (3.65)	7 (4.83)	7 (3.92)	
29	45,129,099	*ss86335405*	7 (4.16)	7 (4.25)	6 (3.72)	6 (4.41)	6 (3.77)	7 (4.25)	
29	45,187,114	*ss86295760*	6 (4.30)	6 (3.97)	6 (3.68)	6 (4.83)	5 (3.52)	6 (4.10)	
29	45,287,502	*ss86312485*	6 (4.45)	6 (3.35)	6 (3.93)	6 (4.76)	6 (3.23)	6 (4.87)	
29	45,326,585	*rs42198683*	7 (4.08)	6 (3.24)	5 (3.51)	6 (4.34)	5 (3.09)	6 (4.52)	
29	45,367,095	*ss86322638*							
29	45,458,280	*rs43706176*							
29	45,482,143	*rs29025626*							
29	45,530,264	*ss86341375*							

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and gree

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relation

[6]-$\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are sh

[7]-$\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum val

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP bl

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

						% V_P explained[9]				
BTA	POS[1]	SNP ID[2]	All Breeds	Angus	Hereford	Charolais	Limousin	Simmental		
7	97,151,592	*rs41656985*								
7	97,261,052	*rs41656987*								
7	97,372,656	*rs41570922*								
7	97,393,157	*rs41615915*								
7	97,430,691	*ss86295638*	0.1069	0.3348	0.3181	0.2968	2.9028	0.5612		
7	97,501,859	*ss86310801*	0.1916	0.2039	0.3081	0.2291	3.8762	0.5472		
7	97,529,872	*ss61472319*	0.3281	0.2727	0.8707	0.2474	3.0739	0.8633		
7	97,691,853	*ss86290016*	0.2342	0.1155	0.7879	0.1839	2.7549	0.1346		
7	97,772,240	*ss86312419*	0.2042	0.1218	0.5156	0.0972	3.3667	1.3058		
7	97,861,341	*rs41593284*	0.1991	0.2543	0.8272	0.8832	4.0170	1.5665		
7	97,898,940	*rs41593281*	0.1880	0.2159	0.3170	0.4538	2.0289	1.6484		
7	97,961,659	*ss117969141*	0.2257	0.3903	0.5856	0.5680	2.9404	1.3240		
7	98,013,150	*ss117968909*	0.2944	0.3231	0.7719	0.7887	3.0408	1.1337		
7	98,173,299	*ss86290989*	0.6082	0.2174	1.5111	0.5415	1.2811	2.2421		
7	98,194,828	*rs41658549*	0.7887	0.7155	1.5810	0.6017	2.1868	2.0381		
7	98,254,815	*rs41658542*	0.8412	0.7193	1.7833	0.4899	2.8748	2.7163		
7	98,375,640	*ss86329349*	0.6480	0.5146	1.7002	0.3179	2.6146	2.7748		
7	98,495,888	*rs43529872*	1.0168	1.3608	1.9218	1.8626	3.2645	1.9619		
7	98,498,047	*ss86321563*	0.6907	0.6996	1.6994	0.9652	2.2145	1.7102		
7	98,538,952	*rs41660170*	0.6994	0.8205	1.8942	2.0957	1.4259	2.4906		
7	98,566,391	*ss117962527*	0.6561	0.6368	1.8793	1.3322	2.1184	0.8685		
7	98,579,574	*rs41255587*	0.5320	0.5029	1.5045	1.1954	1.7032	1.1394		
7	98,635,208	*ss86300200*	0.3645	0.4199	1.3981	0.9644	3.6388	0.3863		
7	98,646,770	*rs41596489*	0.5032	0.3066	1.1240	0.6743	1.6654	1.6151		
7	98,680,293	*ss86315737*	0.2711	0.4693	0.6606	0.6184	3.4188	1.6557		
7	98,726,055	*rs29018251*	0.4022	0.0532	1.3334	1.0384	0.5667	2.4458		
7	98,757,265	*ss86303738*	0.0872	0.0489	0.5442	0.2399	0.4469	1.3233		
7	98,820,742	*ss86324113*	0.2221	0.0468	0.6508	0.5775	0.7773	0.4901		
7	98,887,313	*rs41568595*	0.2211	0.2870	1.0798	1.2957	1.2288	1.2300		
7	98,907,404	*ss86291843*	0.0623	0.0927	0.3782	0.7934	1.3305	0.7421		
7	98,974,456	*ss86339659*	0.1047	0.2045	0.4300	1.6508	3.5200	0.7290		
7	99,024,444	*ss117968912*	0.2343	0.4070	1.1508	1.8810	1.1603	0.2613		
7	99,085,299	*rs41590403*	0.2377	0.2211	1.0249	0.7492	0.9754	0.6307		
7	99,130,598	*ss86333606*	0.1205	0.0478	0.6514	0.5958	2.2676	0.3095		
7	99,178,748	*rs41568774*	0.1257	0.1654	0.3425	0.6688	0.7915	0.6747		
7	99,215,474	*ss86324013*	0.3063	0.2844	1.0966	0.4720	0.3325	1.1453		
7	99,344,820	*rs41622872*	0.1857	0.5936	0.6192	0.1349	1.6586	1.4045		
7	99,399,852	*ss117968895*	0.0522	0.0772	0.2063	0.0734	1.9788	0.1781		
7	99,492,904	*ss86296856*	0.1716	0.1178	0.3100	0.3185	1.8695	0.8208		
7	99,635,841	*ss86339853*	0.1240	0.1541	0.1788	0.3416	3.1080	0.8480		
7	99,687,614	*rs41657025*								
7	99,845,133	*rs41624339*								
7	99,919,908	*ss86339607*								
7	100,015,468	*ss86310226*								
29	42,406,544	*ss86319674*								
29	42,455,680	*ss117974470*								
29	42,620,218	*rs42189770*								
29	42,651,294	*rs43706142*								
29	42,696,595	*rs42189112*	0.0971	0.5927	0.1067	0.4390	0.9426	0.8560		
29	42,749,808	*rs29020063*	0.1618	0.7164	0.1655	0.6353	1.6734	2.4237		
29	42,842,353	*ss117974486*	0.2566	0.5694	0.6020	0.1532	0.9007	2.5806		
29	42,897,144	*ss86322358*	0.1998	1.2397	0.6377	0.3813	1.5694	2.2685		

29	43,006,000	*ss86339964*	0.2243	1.3464	0.5149	0.3115	2.8678	3.3851		
29	43,043,207	*ss86341572*	0.2150	1.2177	0.2691	0.2727	1.1606	2.9719		
29	43,108,445	*ss86337140*	0.2371	1.1154	0.0496	0.0485	1.0267	3.5414		
29	43,129,250	*ss86337549*	0.3180	1.7102	0.1659	0.2836	0.3402	2.3409		
29	43,189,370	*ss86319044*	0.2375	0.7152	0.6429	0.0879	1.1739	1.4806		
29	43,224,753	*rs29013208*	0.3705	1.2772	0.9855	0.0883	0.6477	1.6622		
29	43,269,744	*ss86282762*	0.4843	1.3414	1.0922	0.2052	1.5560	1.8456		
29	43,304,256	*rs29024708*	0.2190	0.6515	0.6304	0.2211	0.5122	2.3447		
29	43,328,607	*ss86295061*	0.2609	1.1412	0.2814	0.9226	0.1729	2.3193		
29	43,429,511	*ss86318094*	0.3438	1.7052	0.7278	0.7317	0.3052	2.7134		
29	43,466,342	*ss86310741*	0.1778	0.6858	0.6546	0.3277	0.1834	1.5918		
29	43,498,073	*ss86338800*	0.2699	1.4302	0.7505	0.6832	1.5707	1.1878		
29	43,611,640	*ss86298040*	0.3270	0.9183	0.6246	0.7037	1.9166	1.9407		
29	43,652,252	*ss86327310*	0.2851	1.2446	0.4059	0.8527	1.6756	2.0019		
29	43,686,401	*ss86325323*	0.3868	1.9641	0.5687	0.7995	0.1161	2.7630		
29	43,709,769	*ss86290081*	0.3391	2.4762	0.4812	0.7101	1.9074	3.2671		
29	43,747,765	*rs42190085*	0.2557	1.1582	0.6285	0.2086	2.1066	3.2947		
29	43,749,527	*ss86299346*	0.2107	0.5996	0.5609	0.5481	2.1140	2.3776		
29	43,777,249	*ss86299989*	0.3691	0.6800	0.7725	0.3275	2.9688	2.3050		
29	43,826,144	*rs42191289*	0.5797	0.6216	1.4613	0.5674	0.6505	2.0858		
29	43,839,783	*ss86336460*	0.1034	0.6447	0.6530	0.2815	0.6028	1.1670		
29	43,914,923	*ss86335514*	0.1333	0.6012	0.2374	0.5500	0.7245	2.0326		
29	44,000,728	*rs42191319*	0.1921	0.1353	0.4667	0.5837	0.6951	1.4871		
29	44,029,526	*rs42192038*	0.1275	0.3279	0.3417	0.6893	1.0148	1.1975		
29	44,042,363	*rs42192064*	0.0646	0.1550	0.4965	0.4318	0.1630	0.2726		
29	44,049,244	*rs42192077*	0.2041	0.5438	0.5527	0.6122	0.0954	1.0924		
29	44,050,471	*ss86284058*	0.2310	0.7920	0.4733	0.4115	1.0465	2.6991		
29	44,051,567	*rs42192079*	0.3953	0.7053	1.0313	0.4786	0.0496	3.5538		
29	44,053,733	*rs42192083*	0.4032	1.0252	0.6287	0.5270	0.4525	3.6792		
29	44,054,901	*rs42192084*	1.1142	1.3904	1.9370	1.3357	0.4794	2.7195		
29	44,058,688	*rs42192090*	0.7568	0.7332	2.0917	1.4072	0.2471	2.7775		
29	44,060,410	*rs42192096*	0.0489	0.5181	0.9330	0.7528	1.0922	0.4018		
29	44,062,694	*rs42192100*	1.1801	0.9229	2.5851	0.8142	1.1448	2.3275		
29	44,063,938	*rs17872078*	1.2277	0.8836	2.4599	1.1151	0.6002	2.9079		
29	44,067,234	*rs17872093*	1.6207	2.2689	2.3735	1.5350	0.9956	5.0523		
29	44,067,796	*rs17871984*	1.8030	2.1985	2.5524	1.9766	1.2721	5.1526		
29	44,068,143	*rs17870631*	1.8519	2.3525	2.4650	1.9660	0.9285	5.3481		
29	44,068,346	*rs17870628*	1.3353	1.9642	1.3739	1.8383	0.7218	4.2853		
29	44,068,445	*rs17870626*	1.3634	3.1851	1.5340	1.8558	0.6257	3.9445		
29	44,068,519	*rs17872010*	1.4843	3.1839	2.3279	2.1726	2.6316	4.4334		
29	44,068,580	*rs17872004*	0.6819	2.0162	1.6311	0.3337	0.9731	2.2337		
29	44,068,812	*rs17872003*	0.2756	0.9369	0.7108	0.7401	0.7367	1.1522		
29	44,069,063	*rs17812000*	1.0159	2.3693	1.1396	1.2239	0.4688	4.6553		
29	44,069,177	*rs17872006*	1.2804	2.5017	1.6476	1.7458	2.0917	4.4879		
29	44,070,713	*rs42192103*	1.2167	2.3723	1.9232	1.9906	2.8836	4.3459		
29	44,070,881	*rs42192105*	1.4070	2.6580	2.2227	2.7550	3.5215	4.2918		
29	44,071,034	*rs42192107*	1.3879	2.5015	2.0222	2.6817	1.5437	4.5974		
29	44,071,135	*rs42192108*	0.4005	1.3964	0.9437	0.7492	1.7837	1.5178		
29	44,071,593	*rs42192109*	0.3764	1.2252	0.8942	0.7841	2.1647	0.6059		
29	44,085,642	*rs17871051*	0.3539	1.6836	0.2326	1.4792	2.5763	3.1650		
29	44,085,769	*rs17871058*	0.7367	2.9196	1.3546	1.4674	2.6655	2.9538		
29	44,087,205	*rs17872032*	0.7179	2.5865	0.6547	0.9348	2.7454	2.9682		
29	44,087,356	*rs17872033*	0.3732	1.1418	0.5388	0.3120	2.9878	1.9136		
29	44,087,629	*rs17872050*	0.3993	0.6251	0.6325	0.9748	1.6848	2.2658		
29	44,087,858	*rs17872151*	0.2942	0.6947	0.9837	0.3630	0.8176	1.4608		

29	44,088,897	*rs17870847*	0.0699	0.4757	0.2390	0.4133	0.2829	0.0973		
29	44,110,295	*rs42192119*	0.2301	0.5087	0.1788	0.6008	0.2157	1.7515		
29	44,119,671	*rs42195143*	0.1902	0.3015	0.5057	0.1852	0.4199	0.7790		
29	44,122,272	*rs42194216*	0.3200	0.2749	0.6289	1.3313	0.7139	1.8567		
29	44,125,747	*rs42194178*	0.2934	0.2900	0.2223	1.4256	0.5045	2.0344		
29	44,130,887	*rs42194132*	0.2816	0.2694	0.2685	0.9360	0.8166	2.1318		
29	44,154,126	*rs42193349*	0.1469	1.3176	0.0735	0.3572	1.1035	1.0763		
29	44,172,614	*ss117965984*	0.0837	1.1845	0.5237	1.3592	0.4293	0.8918		
29	44,196,154	*ss86318958*	0.2808	0.7172	0.9353	0.2450	0.2646	2.2890		
29	44,208,978	*rs29003633*	0.3164	1.2198	0.4870	0.2434	0.3088	1.7895		
29	44,223,148	*ss86323783*	0.2804	0.4551	1.3181	0.5502	0.6021	2.3560		
29	44,243,444	*ss86313099*	0.2925	0.6766	1.3772	0.6640	1.3068	1.8720		
29	44,325,408	*ss86292140*	0.7977	1.0914	1.6889	1.4586	1.6338	1.9225		
29	44,372,611	*ss86329852*	0.2686	0.2614	1.5797	0.2443	1.8282	1.2962		
29	44,395,075	*ss86333994*	0.2678	0.4591	1.5946	0.3017	1.6760	1.2776		
29	44,416,282	*rs43709648*	0.2816	1.1864	0.8254	0.6576	0.3649	2.0519		
29	44,546,564	*ss86288185*	0.6589	1.3387	1.7776	0.6043	0.3169	2.6192		
29	44,585,782	*ss86341172*	0.4103	0.8473	0.6801	0.6665	0.5738	1.7507		
29	44,628,137	*rs41600300*	0.1818	1.1516	0.5392	0.3301	2.4348	2.3067		
29	44,649,908	*ss86337530*	0.2174	0.6102	0.7810	0.9018	1.3420	2.3320		
29	44,740,917	*ss86334185*	0.1446	1.2352	0.3330	0.3502	0.8755	1.7962		
29	44,807,928	*ss117965824*	0.3468	1.6097	0.1538	1.4348	0.7054	1.5679		
29	44,853,970	*rs42192429*	0.3331	2.1742	0.6054	0.2857	2.2915	1.7928		
29	44,900,940	*rs43706228*	0.3513	1.7453	0.7563	0.5117	2.2357	1.1298		
29	44,969,518	*ss86337154*	0.3245	2.1719	0.5930	0.9527	1.4366	0.5132		
29	44,979,377	*ss86338214*	0.1435	0.9229	0.6287	0.4160	0.9712	1.0971		
29	44,999,264	*ss86310727*	0.1378	0.1383	0.4188	0.7578	0.7855	0.8074		
29	45,023,665	*ss86338763*	0.2031	1.1662	0.4889	1.5674	0.4774	1.2544		
29	45,102,557	*ss86332221*	0.1543	0.7558	0.4168	1.7026	1.0905	1.5001		
29	45,129,099	*ss86335405*	0.0505	0.4551	0.2156	0.8526	0.6079	0.3385		
29	45,187,114	*ss86295760*	0.4511	0.3444	1.4206	0.8089	0.4334	0.5176		
29	45,287,502	*ss86312485*	0.2321	1.1501	1.0889	0.5532	0.7580	1.4601		
29	45,326,585	*rs42198683*	0.2840	1.0424	0.9296	0.6741	0.9232	1.0704		
29	45,367,095	*ss86322638*								
29	45,458,280	*rs43706176*								
29	45,482,143	*rs29025626*								
29	45,530,264	*ss86341375*								

[1]UMD3.1 Coordinates. SNPs located within *CAST* and *CAPN1* are shaded in yellow.

[2]Commercialized SNPs are shaded in red.

[3]GBLUP allele substitution effect (α) ranks. Values less than 500 are shaded in yellow for the across-breed and green for the within-breed

[4]GBLUP of SNP allele substitution effects (α) estimated as a random effect.

[5]SNP allele substitution effects (β) estimated as fixed effects in a mixed linear model including the genomic relationship matrix.

[6]$-\log_{10}$(P)-value for the test of the null hypothesis of an allele substitution effect (β) of zero. Maximum values are shaded in red. Other larg

[7]$-\log_{10}$(P)-value for the test of the null hypothesis of all haplotype substitution effects (H) being zero. Maximum values are shaded in red.

[8]Number of haplotypes and effective number of haplotypes in parentheses for the 13 (*CAST*) or 31 (*CAPN1*) SNP block centered on the id

[9]Number Percentage of phenotypic variation in WBSF explained by haplotypes centered on the identified SNP.

